2002-2004
Salt Pilot Project

August 2005

Washington State
Department of Transportation

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Executive Summary

During the winters of 2002-03 and 2003-04, the Washington State Department of Transportation (WSDOT) conducted a field evaluation that compared several aspects of using sodium chloride for highway snow and ice control and corrosion-inhibited snow and ice control chemicals. Sections of highway were designated in which non-inhibited salt products (salt brine and rock salt) were the sole chemicals used. Similar sections of highway were designated in which corrosion-inhibited chemicals (corrosion-inhibited liquid calcium chloride, corrosion-inhibited liquid magnesium chloride, and corrosion-inhibited rock salt) were the sole chemicals used. The aspects evaluated included costs of program delivery, performance, environmental impacts, and corrosion. The main reason for conducting this evaluation was to determine whether or not there was a clear advantage of using one category of chemical over the other.

In terms of costs (labor, equipment, and materials) per lane mile, costs for three test sections (two using salt, one using corrosion-inhibited chemicals) are used to see if there is a clear cost advantage for either category of chemical. Only three of the test sections were selected for the cost comparison. Other sections were not included due to variables (i.e., different traffic volumes, different numbers of on- and off-ramps, different annual snowfall amounts) that would have made for non-viable comparisons. In 2002-03, the costs in one salt section were 40 percent less than the section using corrosion-inhibited chemicals. The costs for the other salt section were similar to the costs in the corrosion-inhibited chemical section. In 2003-04, the costs in one salt section were 3 percent lower than the section using corrosion-inhibited chemicals. The costs for the other salt section were 10 percent higher than the costs in the section using corrosion-inhibited chemicals. This evaluation's data shows no significant and consistent advantage in costs associated with the use of either category of chemical.

Performance, in terms of measured roadway condition during inclement winter weather, was similar between highway sections where salt was used and highway sections where corrosion-inhibited chemicals were used. Maintenance crews using either category of snow and ice control chemical delivered a very high level of service throughout the winter season. They essentially provided bare pavement conditions throughout much of the winter season. The data shows no clear advantage in performance from use of either category of chemical.

In the environmental evaluation, chloride levels found in roadside soils, surface water, and underlying groundwater were found to be generally low and well below any applicable regulatory standards or guidelines. No overall pattern was evident from this evaluation of increased contribution of

chlorides to the roadside environment dependent on whether salt was used or corrosion-inhibited chemicals were used. The data shows no clear advantage regarding environmental impacts from use of either category of chemical.

The corrosion evaluation provided varied results based on different scenarios. Corrosion was evaluated by exposing samples of steel, sheet aluminum, and cast aluminum, in the roadway or roadside environment, to either salt or corrosion-inhibited chemicals and comparing corrosion rates. In eastern Washington, exposure of steel coupons mounted underneath motor vehicles to corrosion-inhibited chemicals consistently resulted in less corrosion than exposure to salt. These figures ranged as high as 70 percent less corrosive than salt and averaged 43 percent less corrosive than salt. This pattern was not evident in the limited test section in western Washington. Where steel coupons were mounted on guardrail posts, there was more corrosion from the exposure to corrosion-inhibited chemicals than from exposure to salt in all scenarios. Corrosion results for sheet aluminum and cast aluminum were less consistent than those found for steel. Amounts of total corrosion on the aluminum coupons were much less than the amount of total corrosion on the steel coupons. Corrosion in aluminum was measured in tenths of grams of weight loss compared to steel that was measured in grams of weight loss. Of the highway sections in eastern Washington using corrosion-inhibited chemicals, those using the calcium chloride liquid product experienced less corrosion than those using the magnesium chloride liquid product. In terms of corrosion to steel on motor vehicles, a clear advantage in reduced corrosion was seen where corrosion inhibited chemicals were used. While a similar advantage was not seen with corrosion in sheet aluminum and cast aluminum, corrosion to steel is much more critical due to the large quantities of steel (compared to aluminum) used in making motor vehicles as well as the greater impacts of corrosion to the structural strength of steel compared to corrosion impacts to aluminum which are largely aesthetic (i.e., surface pitting and discoloration). Within the category of corrosion-inhibited chemicals, the corrosion values were significantly different between the sections where magnesium chloride was used and where calcium chloride were used. If corrosion data from the section using magnesium chloride liquid products is taken out of consideration, the reduced corrosion rates to both steel and aluminum become greater, demonstrating an even clearer, reduced-corrosion advantage associated with the use of corrosion-inhibited chemicals over salt. The corrosion costs to motor vehicles from exposure to salt were not estimated as part of this evaluation.

When the results of the four parameters (cost, performance, environmental impacts, corrosion) for salt and corrosion-inhibited chemicals are compared to each other, the two categories of chemical are fairly similar with the exception of corrosion. While there is no clear-cut advantage of either chemical over the other in terms of costs, performance, and environmental impacts, use of the corrosion-inhibited chemicals showed a clear, corrosion reduction advantage over the use of salt in regards to steel on motor vehicles. While neither salt or corrosion-inhibited chemicals showed a clear advantage regarding corrosion to sheet aluminum and cast aluminum, there was an advantage of reduced corrosion when data from the section using corrosion-inhibited calcium chloride is singled out.

This type of evaluation has provided valuable information for helping to determine WSDOT winter maintenance policy. It will most likely be used in the future to evaluate various types of snow and ice control chemicals and winter maintenance methods.

Background and Research Objectives

Before the late 1980s, WSDOT used sodium chloride in the form of rock salt for the control of snow and ice on highways. Rock salt was used as a supplement to plowing snow and applying abrasives (i.e., sand) onto icy road surfaces. Rock salt was applied to the road surfaces to help melt and breakup compact snow and ice. It was also blended with sand stockpiles to prevent the stockpile from freezing into an unworkable block as well as to add some ice/snow-melting capabilities to traction abrasives. Salt application rates were as high as 800 to 1,000 pounds per lane mile. Additionally, several applications were typically needed if accumulations of snow and ice formed on the roadway before salt was applied.

In the late 1980s, a practice known as anti-icing was becoming more widely utilized by road maintenance organizations. Anti-icing is the practice of applying chemical freeze point depressants to the roadway to prevent the formation of frost or the bonding of snow/ice to the pavement surface. This is commonly achieved by applying a liquid chemical solution to the pavement in advance of a forecast frost or snow weather event. Under many circumstances, anti-icing will provide a safer roadway and be more cost-effective than a traditional plow and sand approach or waiting until snow and ice compacts and bonds to the pavement before chemical treatments are applied.

Many of the snow and ice control chemicals that became available in the late 1980s had corrosion-inhibiting compounds added to mitigate the adverse corrosion impacts from the use of chloride-based compounds. While the costs to purchase these corrosion-inhibited chemicals is significantly higher than sodium chloride, these costs would theoretically be outweighed by the savings from reduced corrosion to motor vehicles, bridges, and other metal-containing highway system components.

Amidst legislative and agency concerns over adverse impacts from using non-corrosion-inhibited sodium chloride (hereafter referred to as “sodium chloride,” “rock salt,” or “salt brine”) and the availability of corrosion-inhibited chemicals, WSDOT made a policy decision to discontinue the use of sodium chloride for highway snow and ice control in the late 1980s. Relatively few other road maintenance organizations have completely discontinued the use of sodium chloride for snow and ice control. Many have evaluated alternative snow and ice control chemicals and have incorporated their use to varying extents. In most cases however, sodium chloride continues to be used solely or predominantly for snow and ice control. This is due to its relatively low price, its utility in helping road maintenance personnel keep roads open during inclement winter weather, its usefulness in providing safe winter driving conditions, improved corrosion protection for motor vehicle construction, acceptance of some levels of corrosion, and doubts about actual reduced corrosion from use of alternative, corrosion-inhibited chemicals.

In the years since this policy change, WSDOT personnel have noticed continued corrosion on maintenance trucks and have received complaints from road users regarding corrosion. On the other hand, WSDOT Bridge personnel have noticed a general decrease in the amount of rehabilitation work needed on bridge decks due to corrosion in the underlying rebar. This conflicting information has caused WSDOT Maintenance personnel to raise the question of how much reduction in corrosion is actually occurring in the roadway environment from the use of corrosion-inhibited chemicals compared to the use of salt. The only documentation of relative corrosion rates from exposure to sodium chloride and corrosion-inhibited chemicals under like circumstances has been from tests conducted under controlled, laboratory conditions. It seemed plausible that differences between the controlled laboratory environment and the variable roadway environment might lead to different rates of relative corrosion.

In addition to the questions about corrosion from snow and ice control chemicals, it was felt that an overall evaluation of sodium chloride as a highway maintenance tool in Washington State was needed. Factors that led to this include sodium chloride's cost-effectiveness, changing anti-icing chemical application practices, other road maintenance organizations' extensive, continued use of sodium chloride, and improved corrosion protection in motor vehicle construction as well as in bridge construction. The use of liquid anti-icers (i.e., salt brine) in a preventive manner results in much lower levels of chlorides being applied to the roadway. Application of chloride-based liquids typically equates to approximately 100 pounds of salt, or chlorides, per lane mile. Contemporary application rates for solid chemicals (i.e., rock salt)), when used for accumulated snow or compact snow and ice, are typically between 200 and 300 pounds per lane mile.

Such an evaluation was conducted during the winter of 2002-03. Because of the relatively mild weather during this winter as well as to see if the results would be consistent in a different winter season, the same evaluation was conducted a second time during the winter of 2003-04. This report supplements the 2002-03 evaluation results with the findings from the 2003-04 evaluation.

Research Objectives

The general objective of this research project was to carry out a multi-faceted comparison of the highway maintenance use of sodium chloride and corrosion-inhibited chemicals under real-world roadway conditions. Specific objectives include:

1. Compare snow and ice control costs of using sodium chloride to like costs using corrosion-inhibited chemicals.
2. Compare the results (i.e., road conditions) of snow and ice control activities carried out by using sodium chloride products to like results from the use of corrosion-inhibited chemicals.
3. Compare corrosion of metal exposed to sodium chloride to metal exposed to corrosion-inhibited chemicals.
4. Compare chloride levels in roadside soils, surface water, and underlying groundwater in areas using sodium chloride to chloride levels in areas using corrosion-inhibited chemicals.

Test Locations

WSDOT initially selected two test locations where salt brine and rock salt would be the sole snow and ice control chemicals used. Two other sections were selected where corrosion-inhibited chemicals were the sole snow and ice chemicals used. Plowing and sanding activities were also conducted as needed in both salt and corrosion-inhibited chemical sections.

Salt Sections

1. I-90 from I-82 Interchange (MP 111/ARM109.29) to Vantage (MP 136.5/ARM134.79) – South Central Region, Maintenance Area 1
2. I-90 from east of Moses Lake (Weber Coulee – MP 191.89/ARM190.18) to Lincoln/Spokane county line (MP 255.29/ARM253.01) – Eastern Region, Maintenance Area 3

Corrosion-inhibited Chemical Sections

1. I-90 from Vantage (MP 136.5/ARM134.79) to east of Moses Lake (Weber Coulee – MP 191.89/ARM190.18) – North Central Region, Maintenance Area 2
2. I-90 from Lincoln/Spokane county line (MP 255.29/ARM253.01) to the Idaho border (MP 299.82/ARM297.52) – Eastern Region, Maintenance Area 1

After the initial planning of the pilot project commenced, maintenance personnel from WSDOT's Southwest Region expressed an interest in participating in the project. SR 6 between Chehalis and Raymond was selected as a section for salt use. A specific section of highway on which corrosion-inhibited chemicals were to be applied was not selected in the Southwest Region for the purpose of comparing data with the salt section. Instead, two maintenance trucks that applied corrosion-inhibited chemicals on several highways in the general vicinity of SR 6 were selected for data comparison purposes.

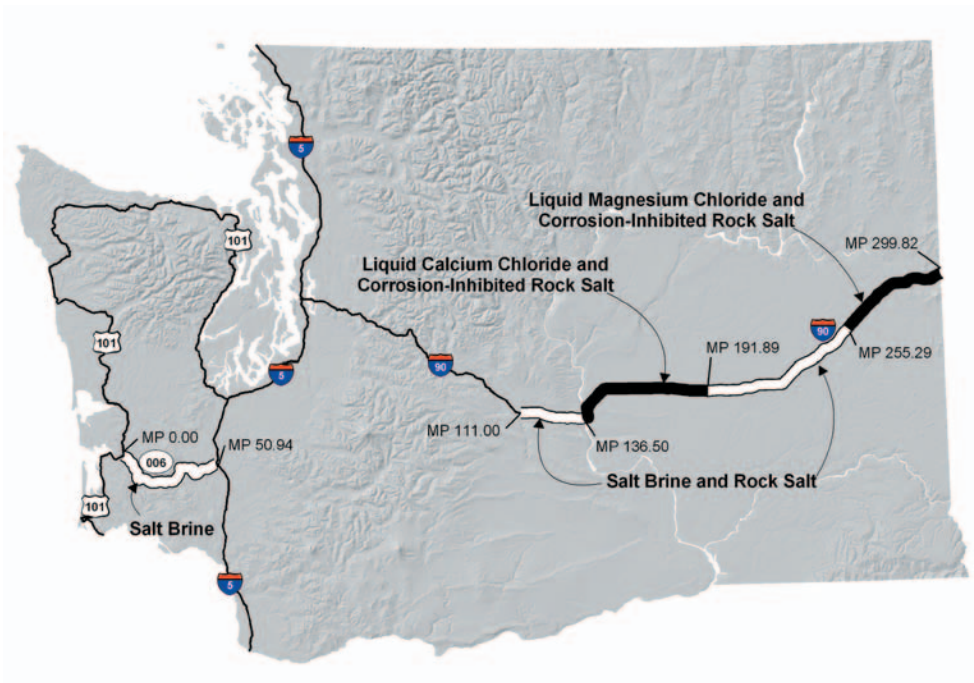


Figure 1: Salt and Corrosion-inhibited Chemical Test Sections

Materials Used

In both of the I-90 salt sections, the liquid anti-icing chemical used was salt brine made by mixing rock salt with water. The brine was mixed to a concentration of 23 percent sodium chloride, as this is the optimal concentration for effective anti-icing of roadways. The correct sodium chloride concentration was determined by using a salinometer. A Varitech SB600 salt brine maker was purchased and used to produce all salt brine used on the I-90 test sections. Rock salt was also used under certain circumstances. The rock salt used in the pilot project was mined and crushed sodium chloride. The same rock salt used directly on the roadway was used to produce salt brine.

In the North Central Region, I-90 corrosion-inhibited chemical section, a corrosion-inhibited, liquid $CaCl_2$ product was used for anti-icing. This material was purchased as a liquid so WSDOT maintenance personnel did not have to perform any mixing or manufacturing of liquid anti-icing chemicals.

The solid chemical used in this section was corrosion-inhibited rock salt. In the Eastern Region, Maintenance Area 1, I-90 corrosion-inhibited chemical section, a corrosion-inhibited, liquid, $MgCl_2$ product was used for anti-icing. This material was purchased as a liquid so WSDOT maintenance personnel did not have to perform any mixing or manufacturing of liquid anti-icing chemicals. The solid chemical used in this section was corrosion-inhibited rock salt.

For the SR 6 salt section, salt brine was made by mixing pre-measured amounts of water and rock salt in a liquid storage tank until the salt dissolved into solution. The correct sodium chloride solution was determined by using a hydrometer. The type of salt used to make brine on SR 6 was a solar salt (dehydrated salt water) that was purchased and stored in 50-pound sacks. No rock salt was applied to SR 6 during this pilot project. In the Southwest Region, the trucks selected for comparison to trucks applying salt brine applied a corrosion-inhibited, liquid, $MgCl_2$ product for anti-icing. No solid chemicals were applied to roadways by these trucks in the Southwest Region.

Snow and Ice Control Methods

All participants in the I-90 pilot project sections agreed to use similar methods of snow and ice control as follows:

1. All lanes of roadway would be anti-iced with liquid chemicals in advance of a forecast frost or snow weather event.
2. If snow began accumulating on the road surface, solid anti-icing chemicals would be applied to prevent compacting and bonding with the pavement.
3. If compact snow and ice formed on the road surface, solid de-icing chemicals would be applied to melt and help break up the snow/ice until bare pavement was regained.
4. If temperatures dropped below the effective use range of chemicals, plowing and/or sanding would be used to provide traction.

On SR 6, liquid salt brine was the only chemical used. Application of salt brine was focused on emphasis areas (i.e., curves, steep grades, intersections) when needed. No solid rock salt was used. Plowing and sanding were to be used as needed.

Liquid anti-icing chemicals were applied to the roadway via either spray trucks or tank trucks. Many of WSDOT's spray trucks are specifically manufactured for herbicide applications during the spring, summer, and fall months but they work very well for applying anti-icing chemicals during the winter. They are equipped with a large tank, motorized pump, computer controls, and spray bars and nozzles for chemical applications. Tank trucks are specifically manufactured for flushing water onto roadways for cleaning or dust control purposes. With minimal alterations, these trucks effectively apply anti-icing chemicals onto the roadway during winter. Solid anti-icing chemicals were applied with dump trucks equipped with hopper/sander units. These trucks were also equipped with pre-wet units so solid anti-icing chemicals could be wetted just before being applied to the roadway for improved adhesion to the road surface and quicker snow/ice melting action.

Winter Weather Severity

Weather conditions affect snow and ice control expenditures and results more than for any other highway maintenance activity. More severe winter weather usually results in higher maintenance expenditures and a reduced ability to keep the highways clear of ice and snow relative to milder winter weather. In reviewing and analyzing maintenance data related to snow and ice, a corresponding measure of winter severity provides a valuable context in which information is considered.

WSDOT utilizes a measure of winter severity based on a measure known as the Winter Index (WI). The winter index was developed as part of a Strategic Highway Research Project (SHRP H-350) specifically for measurement of winter severity in North America. It is a mathematical calculation that produces a numeric weather severity value by using daily temperatures and snowfall data.

$$\mathbf{WI = -25.58\,[TI]^{1/2} + (-35.68)\ \ln((S/10)+1) + (-99.5)\ [(N/(R+10))]^{1/2} + 50}\quad *$$

Temperature Index (TI) – 0 if the minimum air temperature is above 32 F; 1 if the maximum air temperature is above 32 F while the minimum air temperature is at or below 32 F; 2 if the maximum air temperature is at or below 32 F. The averaged daily value is used. (Weighted 35%)

Snowfall (S) – The daily amount of snowfall in millimeters. (Weighted 35%)

Number of Air Frosts (N) – mean daily values of days with minimum air temperature at or below 32 F. (Weighted 30%)

Temperature Range (R) – The difference between the mean monthly maximum air temperature and the mean monthly minimum air temperature. (Weighted 30%)

Figure 2: Winter Index Calculation

Since real-time snowfall information is not available to WSDOT, a modification to the Winter Index is used by WSDOT. The same formula, minus snowfall data, is used and this is termed the Frost Index. WSDOT has compared historical Winter Index ratings and Frost Index ratings and has found a close and consistent correlation between the two. To calculate a Frost Index for the state of Washington, WSDOT uses temperature data from 29 locations that are geographically distributed across the state. Airport temperature information is used, as this is more reliable than information from other, less sophisticated weather information sources. The following chart shows the historical trend in the statewide Frost Index since WSDOT began tracking winter severity.

The statewide Frost Index for the winter of 2002-03 shows a winter season throughout Washington State that was milder than average. This was corroborated by discussions with maintenance personnel in various regions who cited reduced winter maintenance expenditures, low amounts of snowfall, and relatively warm temperatures. The relatively mild winter provided conditions that were conducive for anti-icing in general. Since the general rule of thumb is that salt brine should not be applied at road temperatures lower than 20 F, the warmer temperatures also provided more conditions where sodium chloride could be effectively used compared to winters past.

The statewide Frost Index for the winter of 2003-04 shows a winter season that was closer to average of all winters since WSDOT began tracking winter severity in 1991. The 2003-04 winter season was somewhat variable as it progressed. November and December had colder than average temperatures. The first week of January witnessed a significant, statewide snow/ice weather event on par with something that is seen once every ten years (in western Washington). The remainder of January, February, and March was mild.

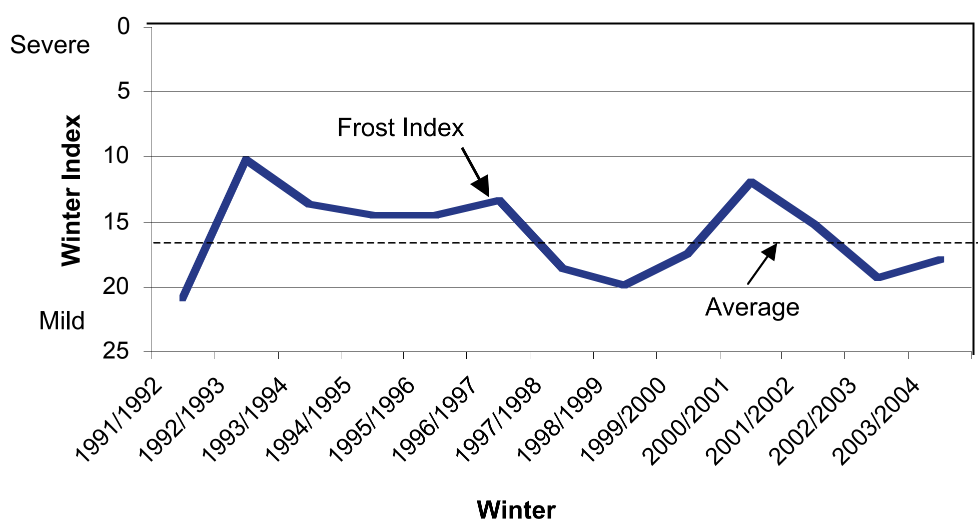


Figure 3: Historical Trend of Winter Severity in Washington State

Costs

Snow and ice control operational costs incurred during the pilot project were tabulated for each project section. The primary objective of documenting these costs was to be able to generate a general comparison of the operational costs of a maintenance program that is reliant on salt products for snow and ice control to a maintenance program that is reliant on corrosion-inhibited chemical products for snow and ice control. Cost items included in this tabulation are materials, labor, and equipment expenditures.

The capital costs to prepare for the pilot project, such as constructing salt sheds and purchasing a brine maker, were not included for the comparison of costs incurred for controlling snow and ice between different project sections. However, the following detail provides cost information on these items for the sake of background information. Seven storage sheds were constructed for the purposes of storing stockpiles of either rock salt or corrosion-inhibited rock salt. Each shed is 34 feet wide and 48 feet deep and constructed with wood pole frames and a steel roof and steel walls down to about six feet from the ground. An asphalt pad served as the floor of each shed and stacked, concrete, ecology blocks comprised the lower walls up to the bottom of the steel walls. Each shed cost a total of approximately $27,000. The brine maker for the Eastern test area cost $7,500 and its insulated, heated housing structure cost $10,000. One 10,500 gallon, liquid storage tank was purchased for $5,000 to be located in the South Central salt section.

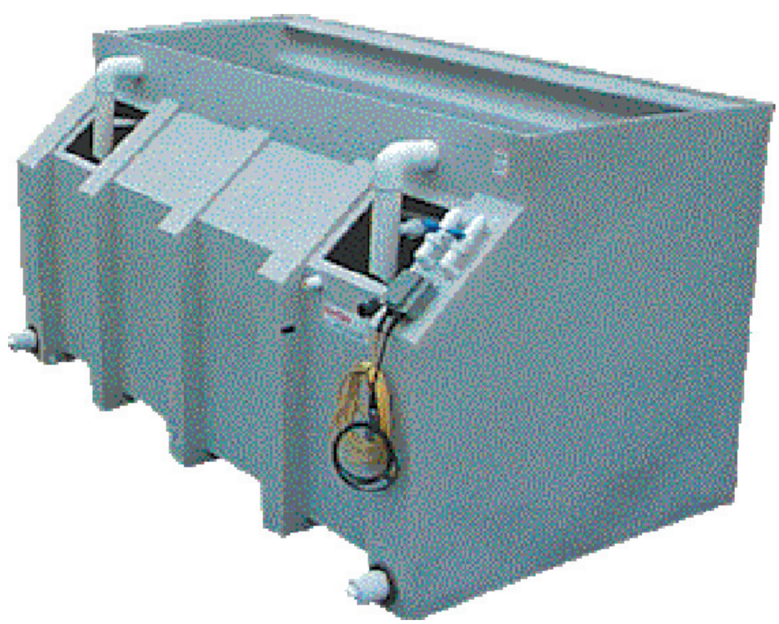


Figure 4: Varitech SB600 Salt Brine Maker

Materials costs are comprised of expenditures to either purchase or make anti-icing chemicals and abrasives that are used for snow and ice control. The cost of salt brine has the labor cost to make the salt brine, and hauling costs when applicable, included as part of the material cost. In eastern Washington, the per-gallon cost of salt brine was approximately two to three times less than that of the corrosion-inhibited, liquid chemicals. Rock salt cost approximately half the amount per ton compared to the corrosion-inhibited solid chemical used by WSDOT. In the Southwest Region where salt brine was made manually by mixing bagged salt and water in storage tanks, salt brine costs were closer to the costs of corrosion-inhibited chemicals.

Equipment costs are comprised of truck use-time expenditures. All trucks used for snow and ice control activities in the pilot project are owned by WSDOT. WSDOT has a revolving fund for trucks and other equipment in which use rates are paid into a fund that ensures replacement of the truck or equipment at the end of its useful life. Non-use rates also contribute to the fund for replacement but only use rates are utilized for the purposes of this project's cost comparison component.

Labor costs are comprised of the wages and benefits paid to highway maintenance workers who carried out snow and ice control activities on test and control sections. Labor expenditures are typically for operating either a truck that plows snow and/or applies abrasives, solid chemicals, or liquid chemicals.

Several variables must be considered when assessing the costs of delivering a winter maintenance program. An example is costs per unit and application rates of anti-icing chemicals. Unit costs vary but so do required application rates. While the unit cost of a certain chemical may only be half of another chemical, the total costs may actually be more if the chemical has to be applied at a much higher rate. Another example is related to the roadway area of responsibility. Total monetary costs between two sections may be similar, but significant differences in miles of roadway maintained will provide important information about program efficiency. A simple way to improve the "fairness" of cost comparisons is to put total costs into terms of costs per lane mile over an entire winter season. While this doesn't factor in every possible variable, it does provide a generally good medium of comparison. The following figure shows the costs per lane mile for both the 2002-03 and 2003-04 winter seasons.

2002-03 Salt Pilot Project Cost Summary

Location	Labor	Equipment	Materials	Lane Miles	$/Lane Mile
SC Region Salt	$10,467	$4,731	$54,479	102	$683
NC Region Corrosion-inhibited Chemicals	$24,347	$12,564	$117,501	222	$696
Eastern Region Salt	$30,090	$13,886	$66,385	253	$436
Eastern Region Corrosion-inhibited Chemicals	$41,492	$18,954	$286,670	210	$1,653
SW Region Salt	$4,042	$1,784	$5,914	103	$114

2003-04 Salt Pilot Project Cost Summary

Location	Labor	Equipment	Materials	Lane Miles	$/Lane Mile
SC Region Salt	$57,000	$26,000	$73,727	102	$1,537
NC Region Corrosion-inhibited Chemicals	$50,838	$36,458	$221,926	222	$1,393
Eastern Region Salt	$72,808	$70,406	$199,292	253	$1,354
Eastern Region Corrosion-inhibited Chemicals	$199,708	$57,049	$360,582	210	$2,940
SW Region Salt	$13,000	$7,602	$10,705	103	$304

Figure 5: Salt Pilot Project Costs per Lane Mile

The across-the-board increase in costs from the first year to the second year of this evaluation is attributable to the more severe winter in 2003-04 compared to that of 2002-03. In terms of costs per lane mile, the most comparable sections are South Central Salt, North Central Corrosion-Inhibited Chemicals, and Eastern Salt. I-90 in these areas is fairly consistent in its rural nature, lower average daily traffic (ADT), and a lower number of interchanges. I-90 in the Eastern Corrosion-Inhibited Chemical section, particularly in the vicinity of the city of Spokane, is urban in nature with high ADT and more interchanges. Additionally, the winter weather in the Spokane area is typically colder and includes more snowfall than do areas to the west. These characteristics drive the cost of winter maintenance higher and therefore skew a comparison with other sections if not adequately considered. The Southwest salt section is in western Washington where the climate is much milder and these costs should not be compared to the costs incurred in eastern Washington.

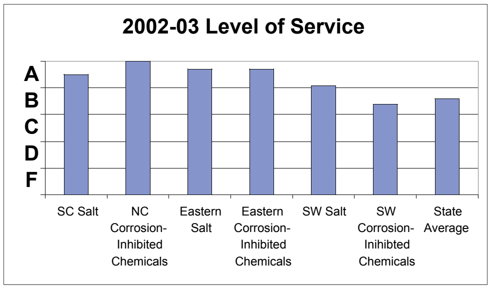
Most noteworthy for this evaluation is that while the cost of salt per unit (tons or gallons) was two to three times less than that of corrosion-inhibited chemicals, operational costs of salt were not consistently lower than the operational costs of corrosion-inhibited chemical use. Saltbrine cost approximately 15 cents/gallon compared with 45 cents/gallon for corrosion-inhibited magnesium chloride and 55 cents/gallon for corrosion-inhibited calcium chloride. Rock salt cost $75/ton compared to corrosion-inhibited rock salt at $130/ton. One of the reasons for similar "per-lane-mile" costs is that salt brine has to be applied at a higher rate than corrosion-inhibited chemicals to get a similar result. Another reason is that the residual time on the roadway for salt brine is less than that of corrosion-inhibited chemicals so salt brine has to be applied more often than corrosion-inhibited chemicals under similar conditions. Additionally, the North Central Region utilized some different equipment and labor approaches (i.e., using larger trucks to avoid returning to the maintenance yard to refill the truck in order to complete a chemical application) where corrosion-inhibited chemicals were used than did the South Central and Eastern Regions where salt was used. This appears to have resulted in cost savings in labor and equipment that help offset the higher costs of corrosion-inhibited chemicals.

Snow and Ice Control Results/Performance

WSDOT measures performance for a variety of maintenance activities using a program known as the Maintenance Accountability Process (MAP). Performance measures are focused on customer-oriented outcomes, or the results of maintenance work with which highway users can identify. Results are typically determined by field evaluations that assess the condition of highway system features. Results are identified in terms of Level of Service (LOS). LOS is communicated in terms of a letter-grade scale similar to school report cards. A LOS of "A" is the best LOS and a LOS of "F" is the poorest LOS.

Throughout the winter season, periodic field evaluations are conducted on randomly-selected segments of highway to assess winter driving conditions. Evaluations are conducted only when conditions producing frost, snow, or ice on the highway are present. These are the conditions that necessitate WSDOT actions (i.e., applying anti-icing chemicals, sand, or plowing snow) to provide for safety and motorist mobility. The condition of the roadway segment is rated on how much bare pavement is provided by anti-icing chemicals or how much sand is present for enhanced traction. Since bare pavement provides better traction than a sanded, icy road surface, a bare pavement outcome will be rated as a higher LOS. A roadway that is maintained in a bare condition will generally be rated as an "A" LOS. A roadway that is maintained as an icy or compact snow and ice surface with abrasives applied on top will generally be rated as a "C" LOS. An icy or compact snow/ice road surface with no abrasives on it will generally be rated as an "F" LOS. Some variations will occur in the LOS ratings dependent on whether or not certain conditions are consistently present on the road or only present on portions of the road. Rating information from each survey is accumulated over a season and the average rating is what determines the LOS delivered over the winter season.

Several roadway segments within the project sections were utilized for field evaluations and LOS calculation. For both the 2002-03 and 2003-04 winters, a summary of the LOS ratings for each project section is shown below. The LOS rating for each section represents the average condition in which the subject roadway was maintained during the winter season.



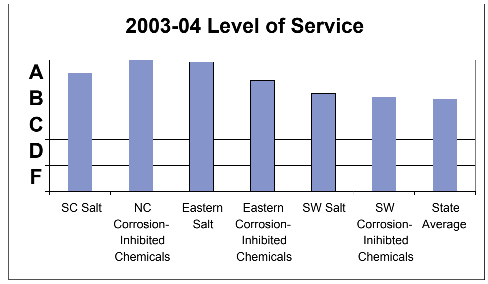


Figure 6: Level of Service Ratings for Project Test Sections

Overall, a high LOS was delivered in all of the project sections during both winter seasons. The aggressive use of chemicals for snow and ice control is the main factor contributing to these results. The small differences in LOS ratings between sections in the South Central, North Central, and Eastern regions are most likely not going to be noticed by the average highway user. The lower LOS in the Southwest salt section reflects a slightly different approach to anti-icing compared to the other project sections on I-90. The Southwest Region focuses anti-icing activities on emphasis areas (i.e., curves, grades, shaded areas) while the other regions anti-ice entire stretches of highway. A more detailed table of the LOS data can be found in Appendix 1.

While the measured results of roads treated with sodium chloride compared to roads treated with corrosion-inhibited chemicals is important, other qualitative performance factors are relevant and should be reported even though they were not specifically measured. In terms of general effectiveness, maintenance personnel found that salt brine was equivalent to corrosion-inhibited chemicals in its ability to prevent frost from forming on pavement surfaces and to prevent snow and ice from bonding to the pavement surface. This is only under the temperature range (approximately 20 degrees or warmer) in which salt should be used. In colder conditions, the effectiveness of salt brine will diminish while other chemicals will continue to work. In some cases, this was a non-issue as when temperatures drop in eastern Washington, frequently, humidity is very low and the pavement is dry and there is no need for anti-icer applications. The dried residual from salt brine applied to the pavement surface was generally found to retain its effectiveness in preventing frost formation or bonding of snow/ice to pavement for one day less than the corrosion-inhibited $MgCl_2$ and $CaCl_2$ products used in control sections. No significant differences were noted between rock salt and the corrosion-inhibited rock salt in their snow/ice melting performance on roadways in project sections.

Regarding handling and working with the liquid anti-icers, maintenance crews found salt brine to be more favorable than the corrosion-inhibited products. One of the reasons is that once the salt brine was made to the correct concentration, the salt would stay in solution during storage without having to be circulated or agitated. The corrosion-inhibited chemicals need to be circulated or agitated while in storage to prevent solids from settling out and diminishing the effectiveness of the remaining liquid product. In regards to washing maintenance trucks and equipment, maintenance crews found the salt brine much easier to wash off than the corrosion-inhibited chemicals. The corrosion inhibited chemicals are sticky and take more effort to wash from trucks and equipment.

Another performance-related issue is chemical slipperiness. This can occur under certain conditions as a liquid anti-icer dehydrates and rehydrates on the pavement surface. During the dehydration/rehydration phase, the chemical can turn into a slippery slurry form as it transitions from a dry form to a wet form or vice versa. In the past, WSDOT has experienced a few instances that appeared to be chemical slipperiness where corrosion-inhibited anti-icers had been used. While these instances were not specifically within any sections of this pilot project, they are still noteworthy in a general comparison of salt brine to other corrosion-inhibited chemicals. Salt brine is generally regarded as less prone to chemical slipperiness than commonly-used corrosion-inhibited chemicals. No instances of chemical slipperiness have been noted in sections where salt brine was used during the pilot project.

Corrosion Standards

WSDOT is a member of a consortium of northwest state DOTs and Canadian provinces known as the Pacific Northwest Snowfighters (PNS). One of PNS's functions is to develop anti-icing chemical specifications that all member organizations utilize. This helps to standardize the market for anti-icing chemicals thus obtaining better pricing and product availability for road maintenance organizations. The PNS specification for corrosion is that a corrosion-inhibited anti-icing chemical must be at least 70 percent less corrosive to steel than sodium chloride. This reduced level of corrosion is determined by a laboratory test.

Generally, the lab test consists of immersing and removing separate steel washers into a sodium chloride solution and a corrosion-inhibited chemical solution. Over a 72-hour period, the washers are immersed for 10 minutes and removed from the solution for 50 minutes. This immersion/removal is done hourly for the 72-hour period. After the test period is complete, the washers are weighed. If the washer exposed to corrosion-inhibited chemicals has at least 70 percent less weight loss compared to the weight loss of the washer exposed to the sodium chloride solution, the corrosion-inhibited chemical meets the PNS specification. The detailed procedure for this test is explained in Appendix 2.

Measuring Corrosion in the Roadway Environment

The field replication of the laboratory corrosion analysis consisted of attaching samples of metal to WSDOT maintenance trucks working on highways where the only anti-icing chemical they would be exposed to is sodium chloride. Similar metal samples were attached to WSDOT maintenance trucks working on highways where the only anti-icing chemical they would be exposed to is a corrosion-inhibited product. In addition to steel, samples of cast aluminum and sheet aluminum were used in this evaluation. Aluminum samples were added because WSDOT receives periodic complaints from citizens regarding corrosion to aluminum components of motor vehicles as well as aluminum boats. Selected trucks were assigned to specific routes for winter maintenance to ensure that they would only be exposed to either type of anti-icing chemical. While the laboratory test uses washers, larger pieces of metal were used for the roadway corrosion test. With longer exposure times and more potential corrosion, it was felt that the smaller washers would be inappropriate for this use. The dimensions of the metal pieces used are approximately 4 inches by 6 inches and are called coupons. Three types of metal were selected based on their common use in the automobile and truck manufacturing industry. Mild steel was selected due to its common use on a wide variety of motor vehicle components. A sheet aluminum alloy (type #5182) was selected due to its use in a variety of car and truck body panels. A cast aluminum alloy (type # A356) was selected due to its use in housings (i.e., transmission housings) of certain car and truck parts.

Each coupon was cleaned, prepared, and weighed. Two coupons of each of the three types of metal were attached to a rack that was in turn attached to WSDOT maintenance trucks. The racks were made of galvanized and painted steel. Coupons were attached to the rack with stainless steel nuts and bolts. Plastic washers were added to the nut and bolt attachments in the second year of the project to help isolate the aluminum coupons from additional corrosion from continuity between dissimilar metals (steel truck chassis and aluminum test coupon).

Each rack (with attached coupons) was then mounted on a truck that was used to conduct snow and ice control activities on the project sections. These were either dump trucks that applied solid chemicals and/or sand or spray trucks or tank trucks that applied liquid chemicals. The coupon racks were fitted between the truck chassis rails in the vicinity of the truck's differential. The coupons and rack were marked for tracking purposes.

Coupons and racks were also fitted onto four supervisor pickup trucks for a similar evaluation. Supervisor trucks are driven on a variety of highways in the course of daily work. In the evaluation, supervisor trucks in the test areas would be driven on highways where they would be exposed to both sodium chloride as well as corrosion-inhibited chemicals. Supervisor trucks in the corrosion-inhibited chemical sections would be driven on highways where they would be exposed only to corrosion-inhibited chemicals since no salt was used anywhere in these maintenance areas.

One set (steel, sheet aluminum, cast aluminum) of coupons was also fitted onto guardrail posts at select locations in each of the project sections. While they do not have the extensive exposure to anti-icing chemicals that WSDOT maintenance trucks have, they have some exposure from stormwater "splash" by vehicles driving on the highways. The guardrail along the project sections of I-90 is typically 10 feet from the nearest travel lane. SR 6 does not have a similar, wide paved shoulder. At the location where the coupons were attached to the guardrail, they were 7 feet from the nearest travel lane.

One set of coupons was also fitted onto fence posts at locations remote to the highway in project sections. These locations had no exposure to anti-icing chemicals on the highway and served to measure "background" corrosion levels from exposure to weather. In project sections on I-90, coupons were attached to fence posts at the back edges of highway rest areas. For SR 6, one set of coupons was attached to a fencepost at a pit site 200 feet off the highway and at another location 150 feet off the highway.

More than 200 coupons were used in the evaluation during each of the winter seasons. After March of each year, all coupons were removed from trucks, guardrail posts, and other locations and sent to the WSDOT Materials Laboratory for completion of the corrosion evaluation. At the lab, all coupons were cleaned, immersed in an acid bath to remove any corrosion, and then weighed to determine weight loss from corrosion.

Corrosion Results

Due to the number of coupons used in the corrosion evaluation, average weight loss amounts were calculated using all coupons of each metal type from each project section. The charts separate corrosion based on the type of metal coupon evaluated. The respective magnitudes of corrosion to different metals are significantly different from each other. Weight loss in the steel coupons was on the order of grams. Weight loss in the sheet aluminum and cast aluminum coupons was much less; on the order of tenths of grams. The charts and narrative for the eastern and western Washington components of the pilot project are reported separately due to the differences in winter weather and snow and ice control methodology. More detailed corrosion information is contained in Appendixes 4 and 5.

Interpreting Corrosion Results

To be included on a WSDOT contract, a vendor must submit samples of their anti-icing chemical and it must meet the corrosion specification (at least 70 percent less corrosive than sodium chloride, corrosion being measured in weight loss) via the lab corrosion test. It also must pass tests for other impurities such as heavy metals. After a product/vendor is included in a WSDOT anti-icer contract, samples are periodically taken of shipments to verify whether or not the product is continuing to meet the required specifications throughout the winter season. Verification is determined through the use of the standard laboratory test for corrosion. Monetary penalties on non-compliance with the corrosion specification can be levied if the product is not at least 65 percent less corrosive than salt per laboratory analysis. The following table shows laboratory corrosion test results for contract compliance monitoring. Each reported result is the average of all corrosion tests conducted on samples taken throughout the winter season.

Product	2002-03	2003-04
Solid Chemical	67%	67%
Liquid $MgCl_2$ (Southwest Region)	65%	71%
Liquid $MgCl_2$ (Eastern Region)	63%	73%
Liquid $CaCl_2$ (North Central Region)	81%	81%

Figure 7: Corrosion Testing – Average Percent Less Corrosive Than Salt

The charts used to depict corrosion rates compare amounts of corrosion in metal samples exposed to corrosion-inhibited chemicals to amounts of corrosion in metal samples exposed to sodium chloride. In the charts for corrosion on steel, the target level of reduced corrosion (70 percent less than salt) is also shown on each measure for corrosion-inhibited chemicals. This way, the reader learns of the "target" (contract specification) and "actual" rates of corrosion. This target is not depicted on the charts for corrosion on aluminum, as the specification applies only to steel. The following is a sample that helps explain how the charts are interpreted:

1. The first comparison (two columns on the left side of the chart) shows corrosion weight loss in coupons attached to maintenance trucks. The coupons that were exposed to salt had an average weight loss from corrosion of 10 grams per coupon as shown in the first column. The PNS target specification of 70% less corrosion than salt means that the target level of corrosion from use of corrosion-inhibited chemicals is 3 grams of weight loss from corrosion (70% of 10 grams equals 7 grams: 10 grams minus 7 grams equals 3 grams). The PNS target is identified by the thick, black bar above the second column. The second column represents the measured weight loss from corrosion in the coupons exposed to corrosion-inhibited chemicals. In this case, the corrosion-inhibited chemicals performed better than expected as they caused less corrosion than the PNS target.

2. The second comparison (middle two columns in chart) shows corrosion weight loss in coupons attached to supervisor trucks. Since the weight loss from corrosion in the coupons exposed to salt is 8 grams, the PNS target specification is 2.4 grams (70% of 8 grams is 5.6 grams; 8 grams minus 5.6 grams equals 2.4 grams). In this case, the corrosion-inhibited chemicals met the specification as their use resulted in the same amount of corrosion as specified by the PNS target.

3. The third comparison (two columns on the right side of the chart) shows corrosion weight loss in coupons attached to guardrail. Since the weight loss from corrosion in the coupons exposed to salt is 11 grams, the PNS target specification is 3.3 grams (70% of 11 grams is 7.7 grams; 11 grams minus 7.7 grams equals 3.3 grams). In this case, the corrosion-inhibited chemicals failed to meet the specification as their use resulted in more corrosion than specified by the PNS target.

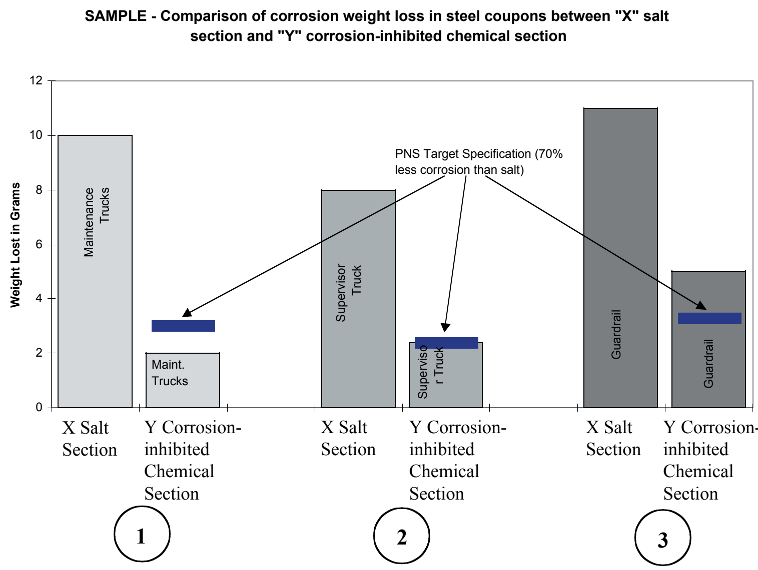


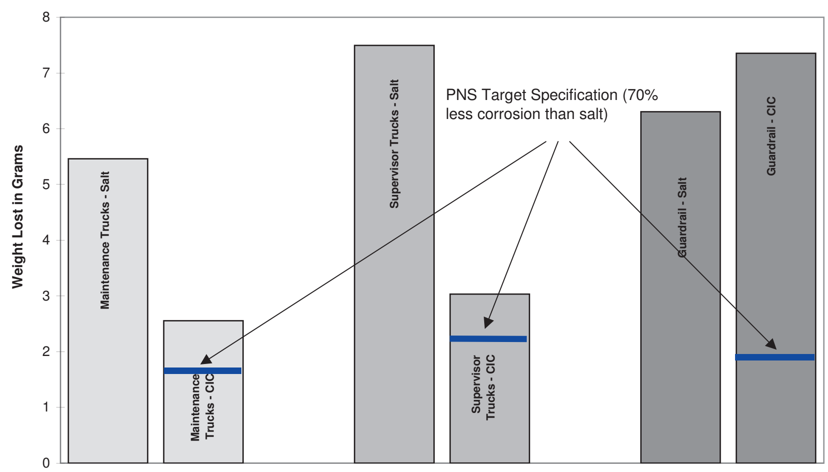
Figure 8: Sample Corrosion Chart

Corrosion Comparison – South Central Region Salt and North Central Region Corrosion-inhibited Chemicals

Comparisons of corrosion weight loss from sodium chloride exposure to corrosion weight loss from corrosion-inhibited chemical exposure are made between the South Central salt section and the North Central corrosion-inhibited chemical section as well as between the Eastern Region salt and corrosion-inhibited chemical sections. South Central and North Central are geographically adjacent to each other and each had coupons from two maintenance trucks. The two Eastern region sections are adjacent and the salt section had coupons on nine trucks and the corrosion-inhibited chemical section had coupons on ten trucks.

The following charts show corrosion in steel coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the South Central salt and the North Central corrosion-inhibited chemical sections. The coupons mounted on maintenance trucks and supervisor trucks that were exposed to corrosion-inhibited chemicals had significantly less corrosion than similar coupons exposed to salt. The amount of reduced corrosion in the roadway environment came fairly close to levels of corrosion determined by laboratory tests. However, the guardrail-mounted coupons exposed to corrosion-inhibited chemicals had more corrosion than similar coupons exposed to salt. These corrosion patterns were consistent between the two years of evaluation.

2002-03 Comparison of corrosion weight loss in steel coupons between SC Salt section and NC corrosion-inhibited chemical (CIC) section



2003-04 Comparison of corrosion weight loss in steel coupons between SC Salt section and NC corrosion-inhibited chemical (CIC) section

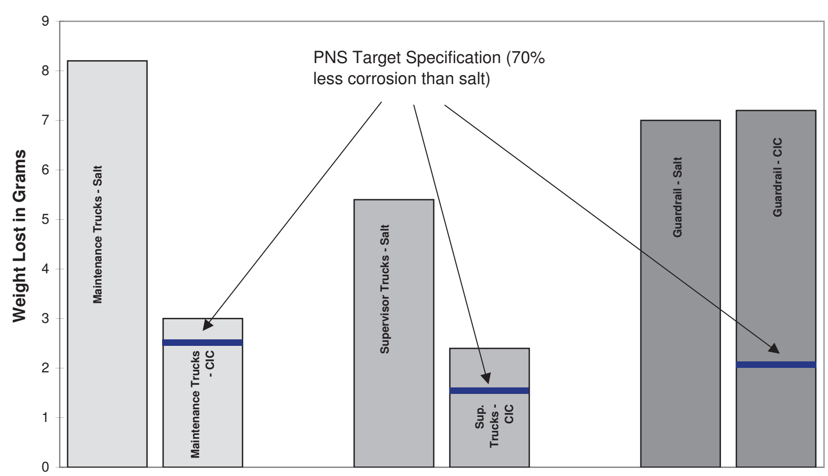
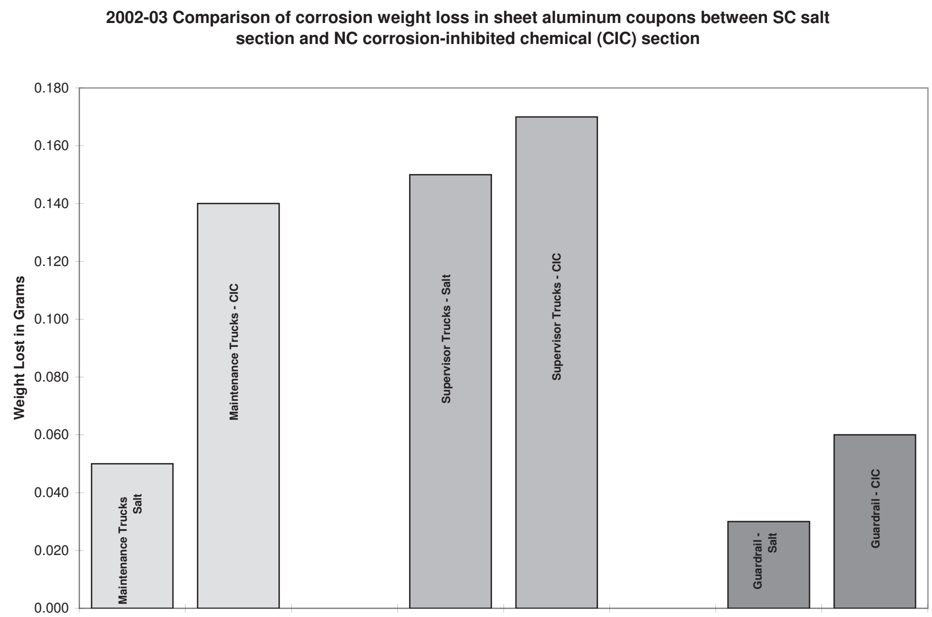


Figure 9: Steel Coupon Corrosion in South Central and North Central Region Test Sections

The following charts show corrosion in sheet aluminum coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the South Central salt and the North Central corrosion-inhibited chemical sections. Corrosion results from coupons mounted on maintenance trucks and supervisor trucks were not consistent between the two winter seasons. Corrosion on the guardrail-mounted coupons was similar in the two years of evaluation.



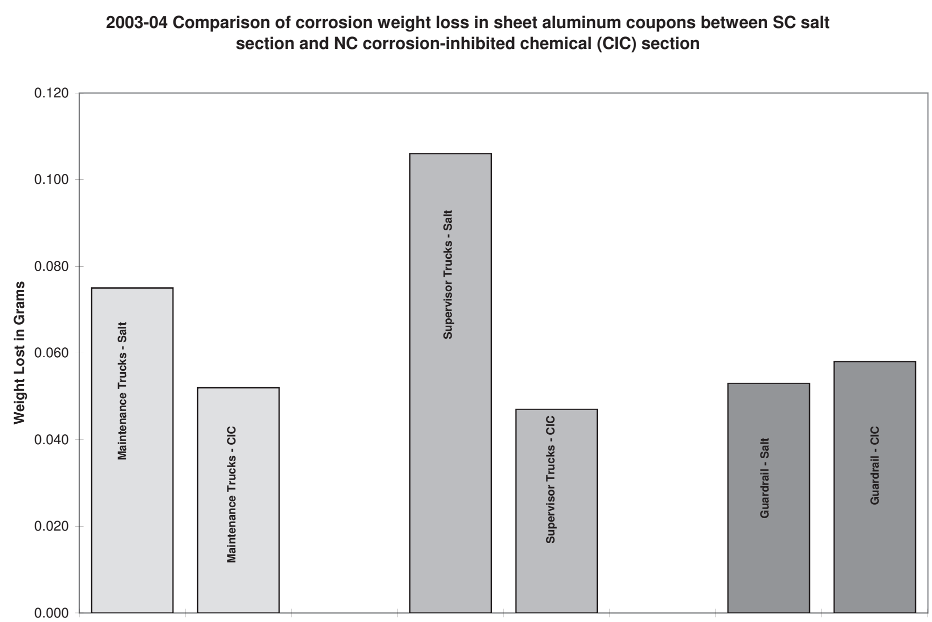
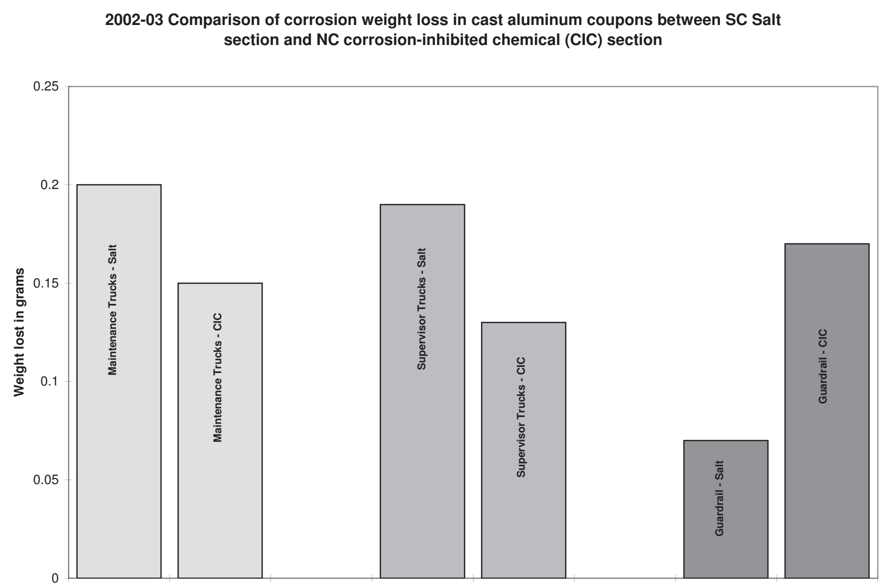


Figure 10: Sheet Aluminum Coupon Corrosion in South Central and North Central Region Test Sections

The following charts show corrosion in cast aluminum coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the South Central salt and the North Central corrosion-inhibited chemical sections. The coupons mounted on maintenance trucks and supervisor trucks that were exposed to corrosion-inhibited chemicals had less corrosion than similar coupons exposed to salt. However, the guardrail-mounted coupons exposed to corrosion-inhibited chemicals had more corrosion than similar coupons exposed to salt. These corrosion patterns were consistent between the two years of evaluation.



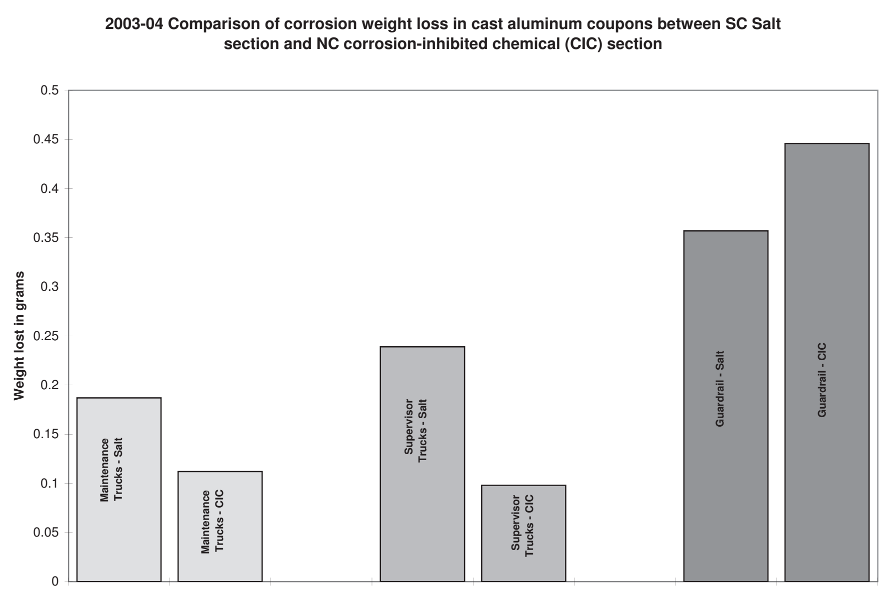
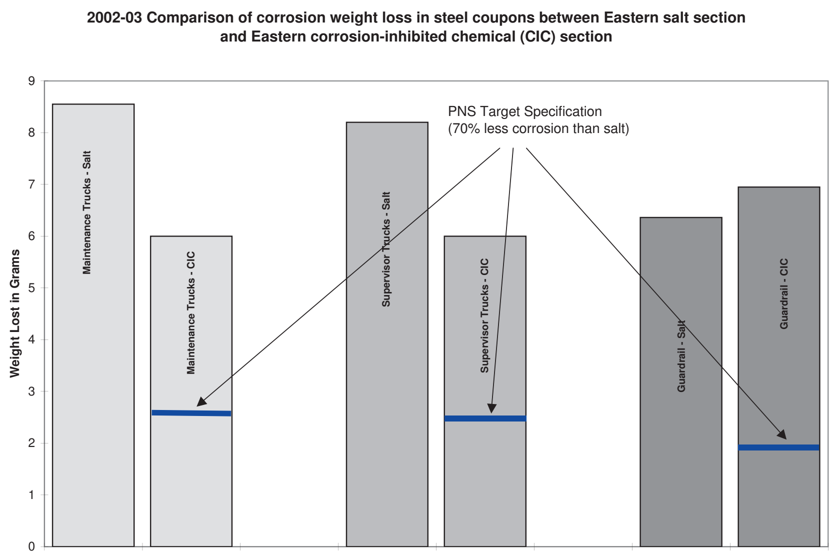


Figure 11: Cast Aluminum Coupon Corrosion in South Central and North Central Region Test Sections

Corrosion Comparison – Eastern Region Salt and Corrosion-inhibited Chemicals

The next charts show corrosion in steel coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the Eastern Region salt and corrosion-inhibited chemical sections. The coupons mounted on maintenance trucks and supervisor trucks that were exposed to corrosion-inhibited chemicals had moderately less corrosion than similar coupons exposed to salt. However, the guardrail-mounted coupons exposed to corrosion-inhibited chemicals had more corrosion than similar coupons exposed to salt. These corrosion patterns were consistent between the two years of evaluation.



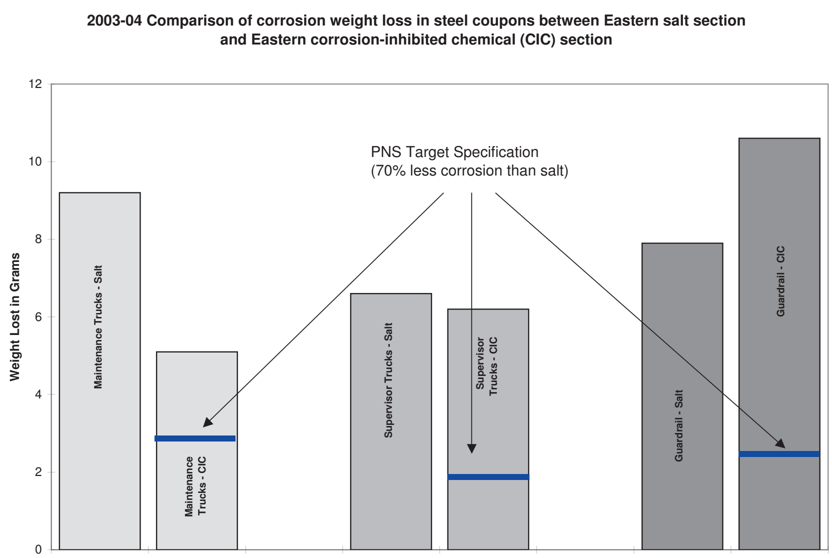
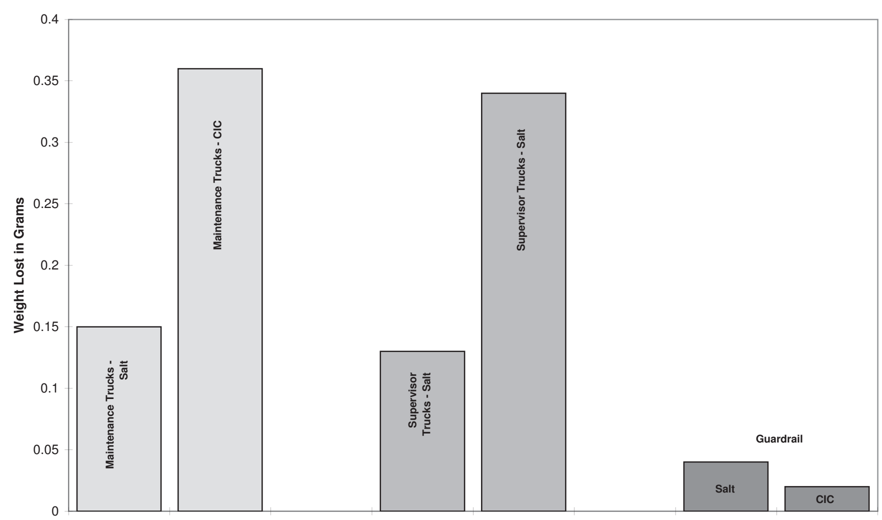


Figure 12: Steel Coupon Corrosion in Eastern Region Test Sections

The following charts show corrosion in sheet aluminum coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the Eastern Region salt and corrosion-inhibited chemical sections. During both winter seasons, coupons mounted on maintenance trucks and supervisor trucks had more corrosion from exposure to the corrosion-inhibited chemicals than the exposure to salt. The results were inconsistent between the two years of evaluation for coupons attached to guardrail posts.

2002-03 Comparison of corrosion weight loss in sheet aluminum coupons between Eastern salt section and Eastern corrosion-inhibited chemical (CIC) section



2003-04 Comparison of corrosion weight loss in sheet aluminum coupons between Eastern salt section and Eastern corrosion-inhibited chemical (CIC) section

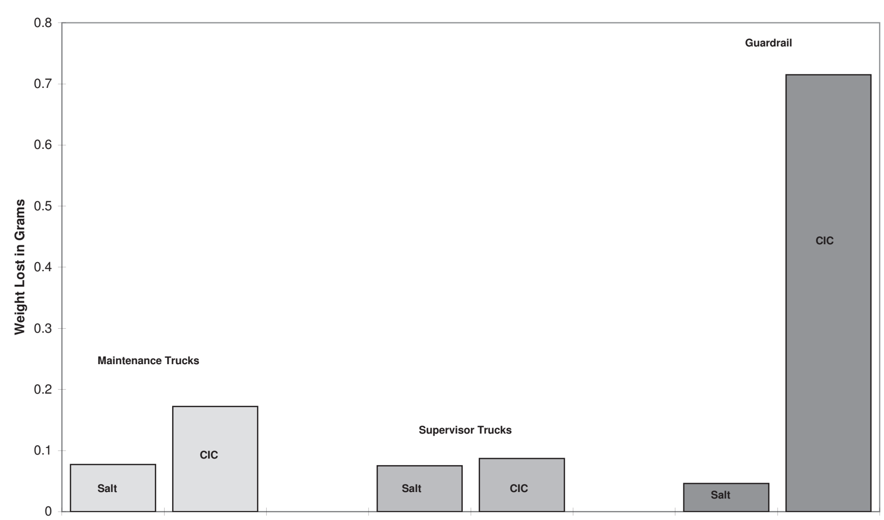
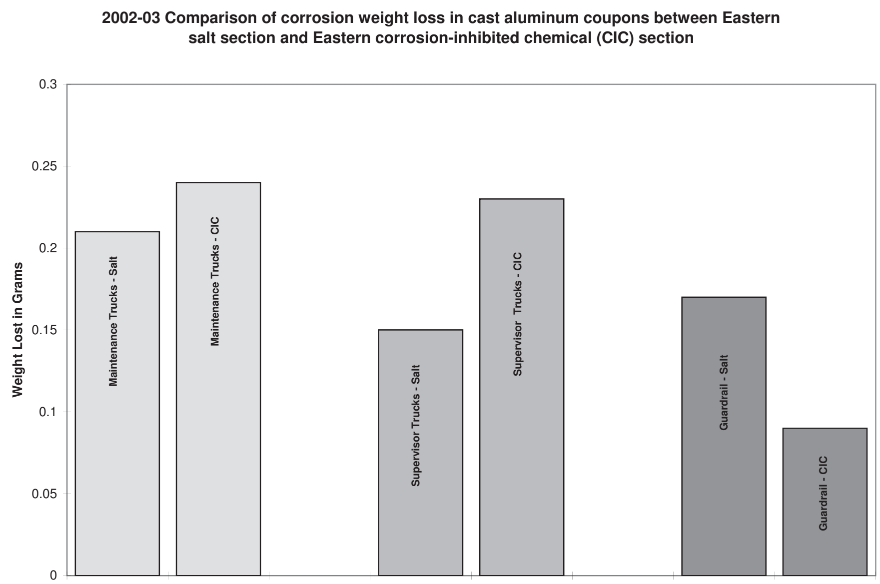


Figure 13: Sheet Aluminum Coupon Corrosion in Eastern Region Test Sections

The following charts show corrosion in cast aluminum coupons mounted on maintenance trucks, supervisor trucks, and guardrail in the Eastern Region salt and corrosion-inhibited chemical sections. During both winter seasons, coupons mounted on maintenance trucks and supervisor trucks had more corrosion from exposure to the corrosion-inhibited chemicals than the exposure to salt. The results were inconsistent between the two years of evaluation for coupons attached to guardrail posts.



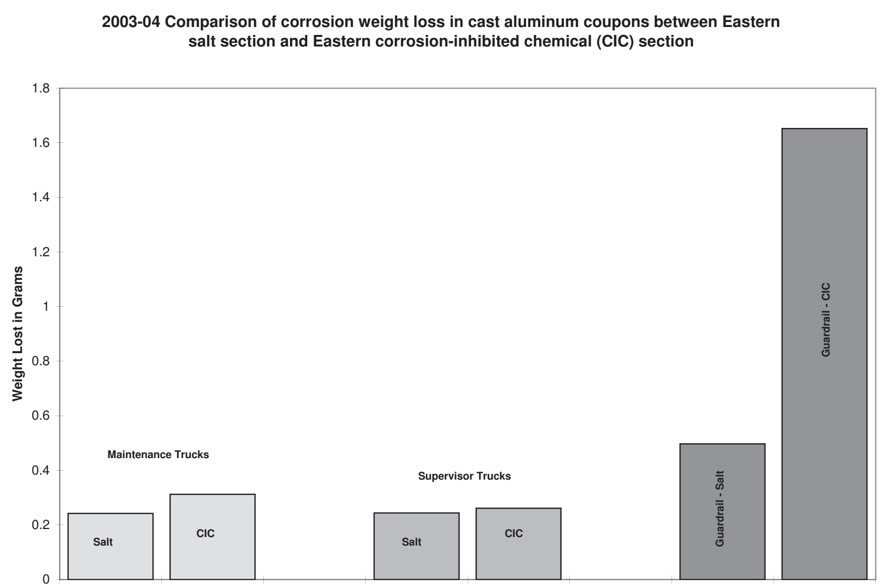


Figure 14: Cast Aluminum Coupon Corrosion in Eastern Region Test Sections

Discussion

WSDOT maintenance trucks have more intensive exposure to anti-icing chemicals than other motor vehicles on the highways. Maintenance trucks carry loads of the chemicals, they are used to apply the chemicals, and they are driven on the highways where chemicals can be applied several times per day. For these reasons, maintenance trucks could be viewed as the “worst case scenario” in evaluating corrosion caused by anti-icing chemicals. The majority of the corrosion coupons used in this evaluation were placed on maintenance trucks.

The steel coupons that were attached to maintenance trucks and supervisor trucks indicate that corrosion-inhibited chemicals provided some reductions (up to 70 percent) to corrosion rates compared to corrosion rates of sodium chloride. While these reductions generally fell short of comparable results from laboratory corrosion analysis and the PNS corrosion specification, they indicate some value in reduced corrosion to steel in motor vehicles. Of the two corrosion-inhibited liquid chemicals used in the corrosion-inhibited chemical sections, the section using the liquid, calcium chloride product showed better corrosion reduction than the section using the liquid magnesium chloride product in both lab analysis as well as corrosion in the truck-mounted, steel coupons. In some cases with both types of aluminum coupons that were attached to maintenance trucks, the corrosion rates from exposure to corrosion-inhibited chemicals were actually higher than in exposure to sodium chloride.

The supervisor pickup truck represents a lesser degree of exposure to anti-icing chemicals than does the maintenance truck. On average, the supervisor pickup truck is driven on highways once or twice per day as the supervisor inspects highway features, checks on maintenance operations and completed work, and otherwise oversees the daily maintenance and operations of the highway. In terms of exposure to corrosion, the supervisor pickup truck is closer to the citizen motor vehicle that is used on the highway for a daily work commute.

Both the steel and aluminum coupons mounted on the supervisor pickup trucks showed corrosion rates similar to the coupons from the maintenance trucks. For steel coupons, corrosion in the corrosion-inhibited control sections was less than that in the salt sections but short of the PNS specification level. For the aluminum coupons, more corrosion was experienced from salt exposure in some cases and in others, more corrosion was experienced from exposure to corrosion-inhibited chemicals.

The following table aggregates two years worth of corrosion data for each type of metal tested from all eastern Washington maintenance trucks and supervisor trucks. Corrosion data from the section where liquid calcium chloride was used is also broken out separately from the data from the section where liquid magnesium chloride was used. The data shows that the most reduction in corrosion was experienced in the section where liquid calcium chloride was used.

Average Weight Loss (in grams) from Corrosion

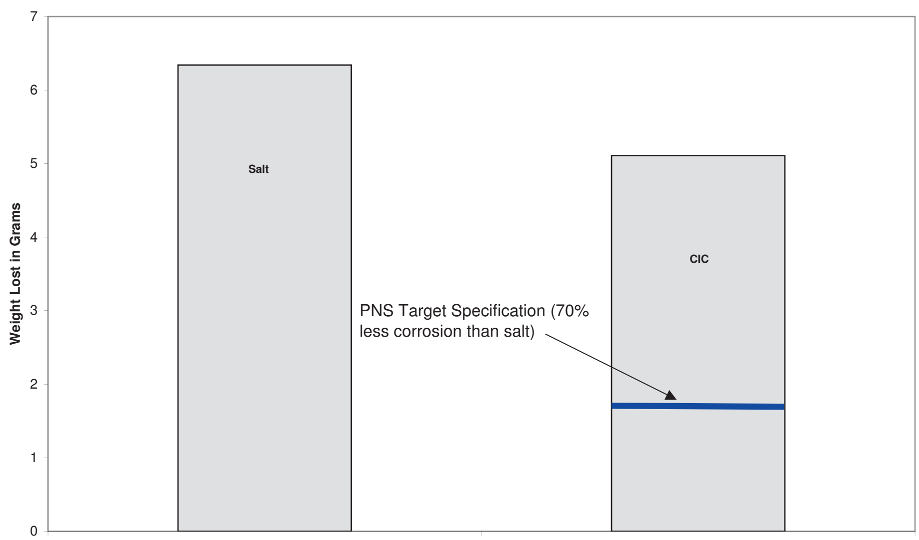
	Steel	Sheet Aluminum	Cast Aluminum
Salt	7.4	0.101	0.199
Calcium Chloride	2.6	0.101	0.12
Magnesium Chloride	5.8	0.241	0.32

Coupons mounted on guardrail posts have a less intensive type of exposure than do coupons mounted on maintenance trucks or supervisor pickup trucks. These coupons are exposed to anti-icing chemicals through splash from traffic, some occasional snow or slush that is cast off the highway by a snowplow, and water/chemical that is turned into a mist or fog by traffic action. While the corrosion-inhibited chemicals resulted in some levels of reduced corrosion to steel coupons on maintenance and supervisor trucks, this was not the case with steel coupons mounted on guardrail posts. There was more corrosion on guardrail-mounted steel coupons exposed to corrosion-inhibited chemicals than those exposed to salt. Additionally, the total amount of corrosion on these coupons was generally similar to the total amount of corrosion on the truck-mounted coupons. While the reasons for this are unknown, it does raise the question of whether or not corrosion inhibitors are providing any actual corrosion reduction on bridges. If corrosion rates associated with corrosion-inhibited chemicals increase as they migrate 10 feet from where they are applied to the roadway, will they also increase as the chemicals migrate into bridge decks through pavement cracks or drip down onto structural components of the bridge below the bridge deck? This corrosion information indicates that the PNS specification and accompanying laboratory procedure has some level of correlation with corrosion that actually occurs to steel in motor vehicles. The information does not demonstrate a correlation between the specification/lab test and aluminum or steel on the roadside.

Corrosion Comparison – Southwest Region Salt and Corrosion-inhibited Chemicals

In the comparison of corrosion in steel coupons mounted on Southwest Region salt and corrosion-inhibited magnesium chloride maintenance trucks during the winter of 2002-03, the coupons exposed to corrosion-inhibited magnesium chloride had 19 percent less corrosion than similar coupons exposed to salt. In 2003-04, the coupons exposed to corrosion-inhibited magnesium chloride had 57 percent more corrosion than similar coupons exposed to salt.

2002-03 Comparison of corrosion weight loss in steel coupons between SW salt section and SW corrosion-inhibited chemical (CIC) section



2003-04 Comparison of corrosion weight loss in steel coupons, mounted on maintenance trucks, between SW salt section and SW corrosion-inhibited chemical (CIC) section

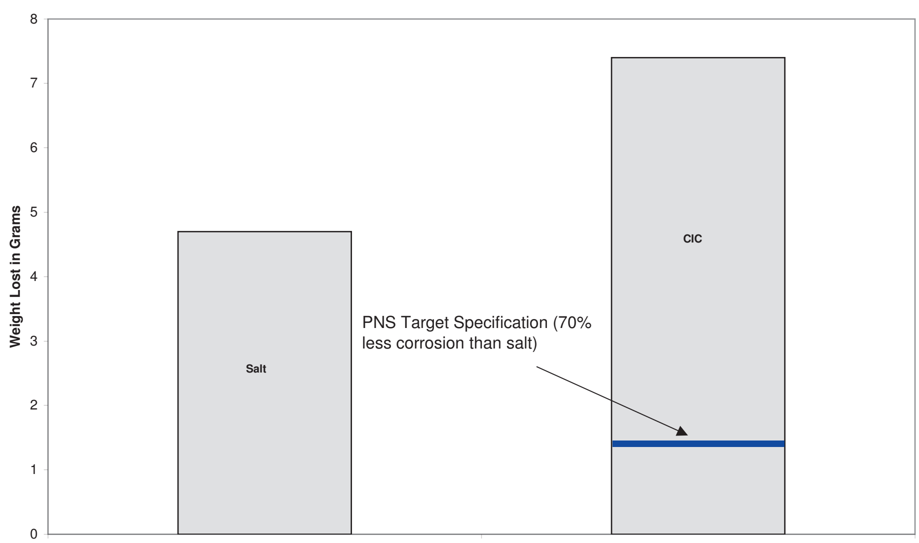
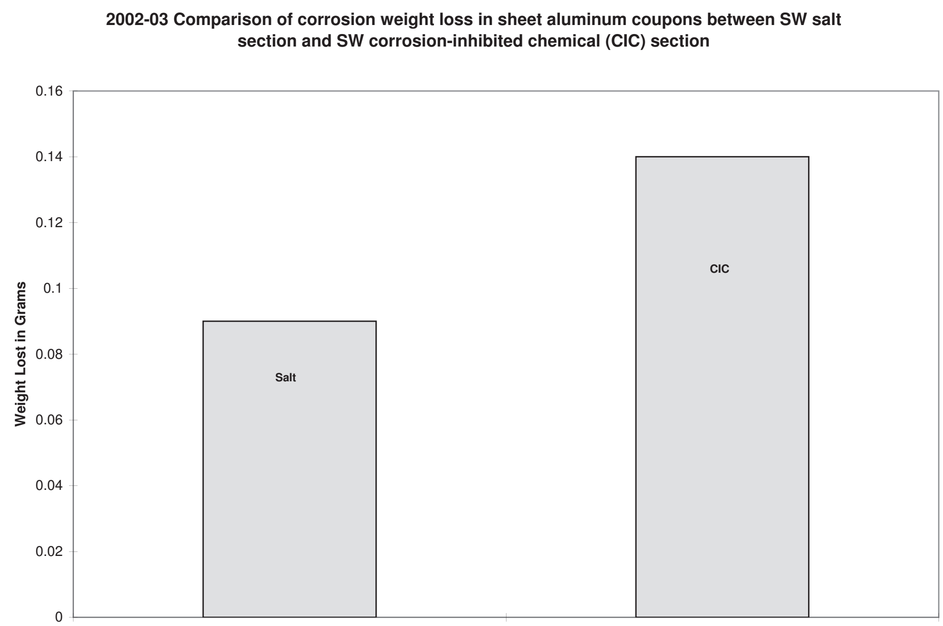


Figure 15: Steel Coupon Corrosion in Southwest Region Test Sections

The next comparison shows the average weight loss of sheet aluminum coupons mounted on Southwest salt and corrosion-inhibited magnesium chloride maintenance trucks. During both winter seasons, the coupons exposed to corrosion-inhibited magnesium chloride had more corrosion than similar coupons exposed to salt.



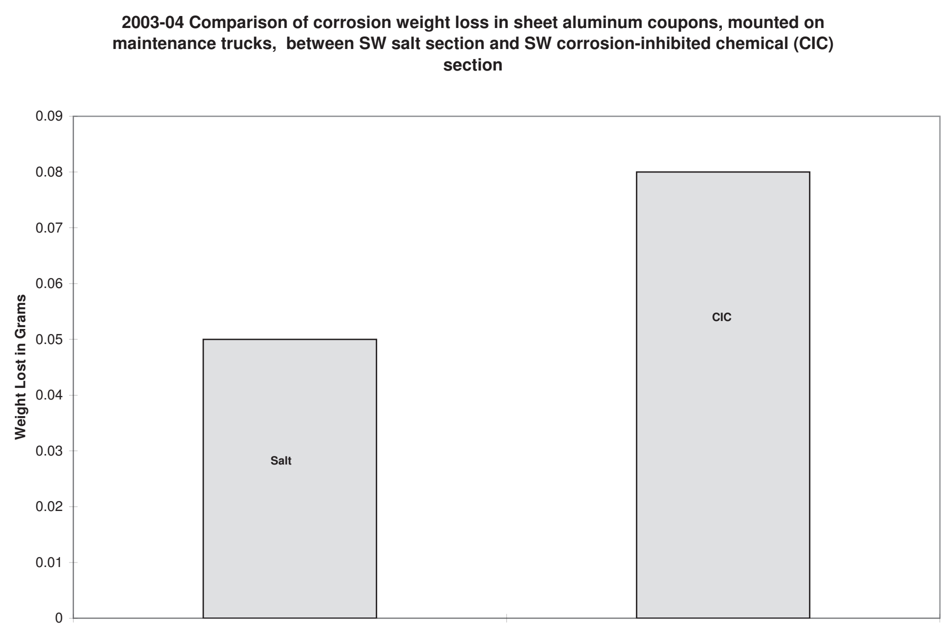


Figure 16: Sheet Aluminum Coupon Corrosion in Southwest Region Test Sections

The next comparison shows the average weight loss of cast aluminum coupons mounted on Southwest salt and corrosion-inhibited magnesium chloride maintenance trucks. During both winter seasons, the coupons exposed to corrosion-inhibited magnesium chloride had more corrosion than similar coupons exposed to salt.

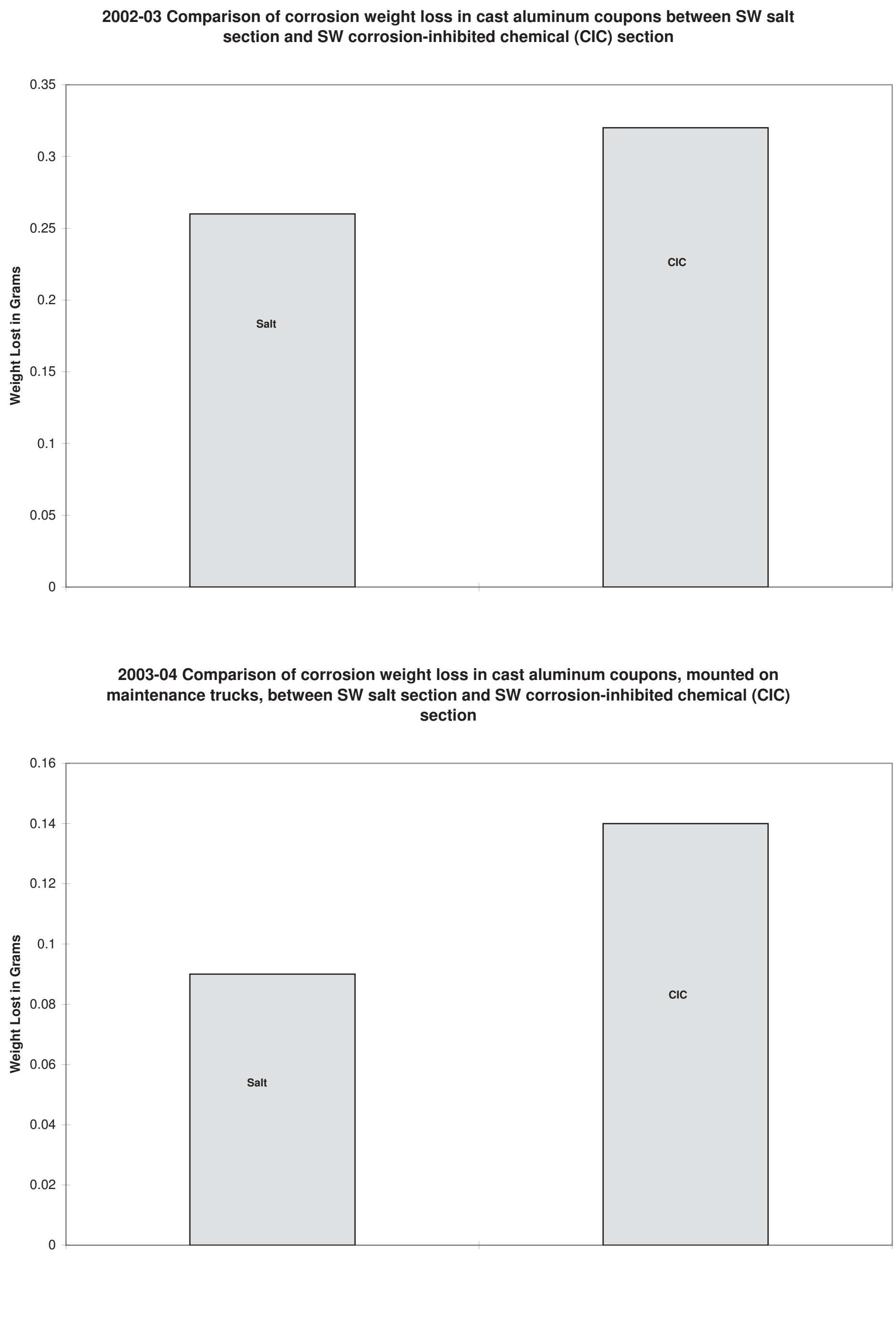


Figure 17: Cast Aluminum Coupon Corrosion in Southwest Region Test Sections

Discussion

The relative, average corrosion rates found in coupons used on SR 6 in western Washington were somewhat different from those found in coupons used in eastern Washington. For steel coupons, the corrosion-inhibited chemicals appeared to provide little to no reduction of corrosion for steel on maintenance trucks. All scenarios with aluminum coupons showed more corrosion from exposure to corrosion-inhibited magnesium chloride than exposure to salt. No coupons were placed on guardrail posts in western Washington where corrosion-inhibited chemicals were used so comparison data with sodium chloride-exposed coupons is not possible.

Bridge Corrosion

From a bridge preservation standpoint, areas of concern related to corrosion from anti-icing chemical applications focus primarily on rebar within bridge decks, metal barriers on bridges, and steel structural components underneath the bridge deck. WSDOT bridge office personnel reported no noticeable variations in corrosion levels on any metallic elements of bridges that underwent routine inspections in the salt and corrosion-inhibited chemical sections. It was felt that no meaningful evaluation of corrosion on bridge components could take place in the relatively short time during which this research was conducted. A bridge corrosion evaluation would most likely have to be a multi-year evaluation to generate meaningful information related to actual structural bridge corrosion rates. These issues would be similar to study corrosion levels of dowel bars or tie bars in concrete pavements.

Environmental Impacts

As part of this pilot project, WSDOT environmental staff conducted field sampling and laboratory analysis to assess the level of chloride residue in the roadside environment. Similar to the other components of this evaluation, the environmental analysis focused on differences in chloride residue in the soil and water for the areas using corrosion inhibited chemicals and those using sodium chloride. The State Departments of Health (responsible for regulation of drinking water) and Ecology (responsible for regulation of surface and ground water) were advised of the pilot project and notified that field measurements would be made. Chloride at a concentration of 250 mg/l is a secondary drinking water standard for taste only. A secondary drinking water standard serves as a guideline and is used by regulatory agencies for chlorides instead of an actively enforced primary standard. Primary standards are used for substances that pose greater potential threats due to toxicity or other dangerous properties. Levels of chloride averaging approximately 40mg/l occur naturally in Washington State drinking water. Chloride is not classified as a toxic substance by Washington State resource agencies. Studies have found that different plant species have widely ranging tolerance levels to chlorides. In general terms, research has shown that freshwater fish begin to demonstrate ill effects from chloride exposure at concentrations between 4000 and 5000 mg/l.

Sampling Methodology

Within each of the four designated sections along I-90 (two sections using corrosion inhibited chemicals and two sections using sodium chloride), four sample locations were identified. These locations were generally chosen based on the potential for chlorides from highway snow and ice control activities to enter nearby waters. However, due to the semi-arid nature of the Columbia River basin, some sections did not have any water bodies nearby that were suitable for sampling. Two sample locations along SR 6 were selected at which standing water was present. All sample locations were recorded into a global positioning system. In 2002-03, the mild winter weather did not afford ample opportunity for significant sampling opportunities (i.e., runoff from a major snowmelt) during the winter season. In 2003-04, cold temperatures persisted all winter long and there was no snowmelt event until spring. As such, only pre-winter and post-winter sampling was conducted for the environmental analysis.

Surface soil samples were collected from each location adjacent to the edge of the pavement, ten feet from the edge of the pavement, and in the sediment at the bottom of a roadside ditch or pond if present (see Figure 19). Samples were taken at an approximate depth of three inches below the surface. Care was taken to not include excess organic matter and to minimize the number of rocks present in the sample material.

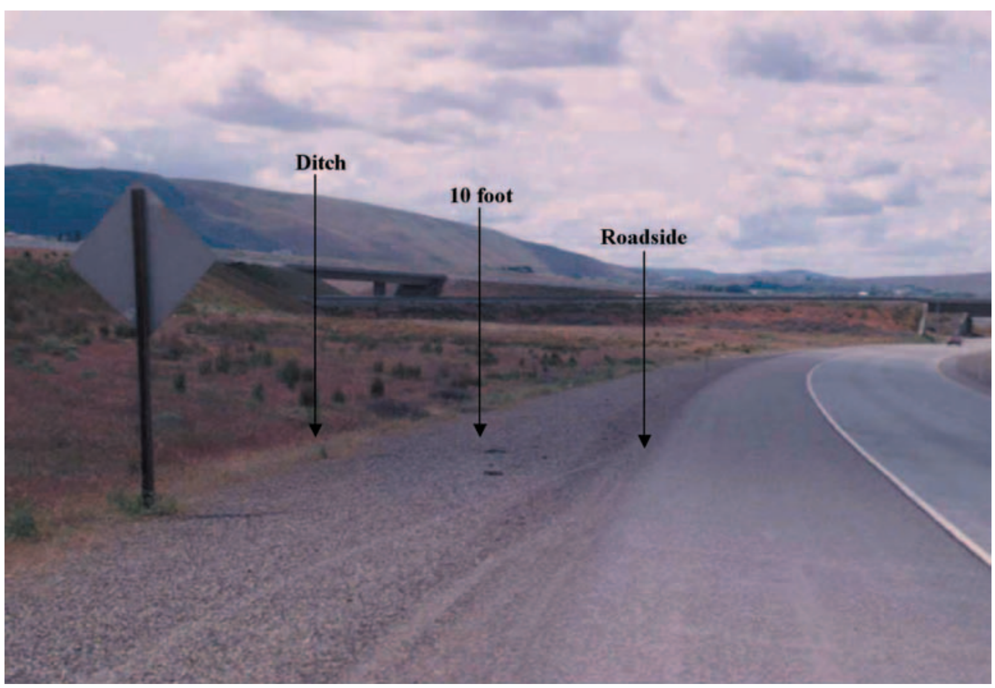


Figure 18: Representation of Soil Sampling Locations

Surface water bodies were sampled only if they were considered non-flowing, e.g., ponds, lakes. Flowing water bodies were not selected because of the dilution factor. Several past studies have shown that in flowing water, chlorides are rapidly diluted leaving little to no detectable chlorides.

One control location was identified within each of the four I-90 segments to measure background chloride levels. These were selected based on the likelihood that the location would be unaffected by any snow and ice control activities. These sites were located at least 100 feet from any roadway or sidewalk. A designated ground water sample was also obtained from each I-90 section from water fountains located at Safety Rest Areas. Each of the Rest Areas is served by a WSDOT-owned well which serves the Rest Area only.

The pre-winter sampling events occurred during the summer and fall preceding each winter season. The post-winter sampling events occurred during the spring following each winter season. The pre-winter and post-winter samples were collected within one foot of each other. Severn Trent Laboratories of Seattle, Washington, analyzed all samples for total chloride using analytical method USEPA 300A.

Sample Results

The numerical data for each sample can be found in Appendix 6. Only data from eastern Washington test sections is used in the following charts.

Soil Chlorides Comparisons – Salt Sections and Corrosion-inhibited Chemical Section

The following chart shows comparisons of chloride levels in soils in the salt sections and the corrosion-inhibited chemical sections before the 2002-03 winter season commenced. Each column represents the average of all pre-winter samples taken at each location. Overall levels of chlorides are relatively low falling well below levels that would generate concern related to environmental or health protection.

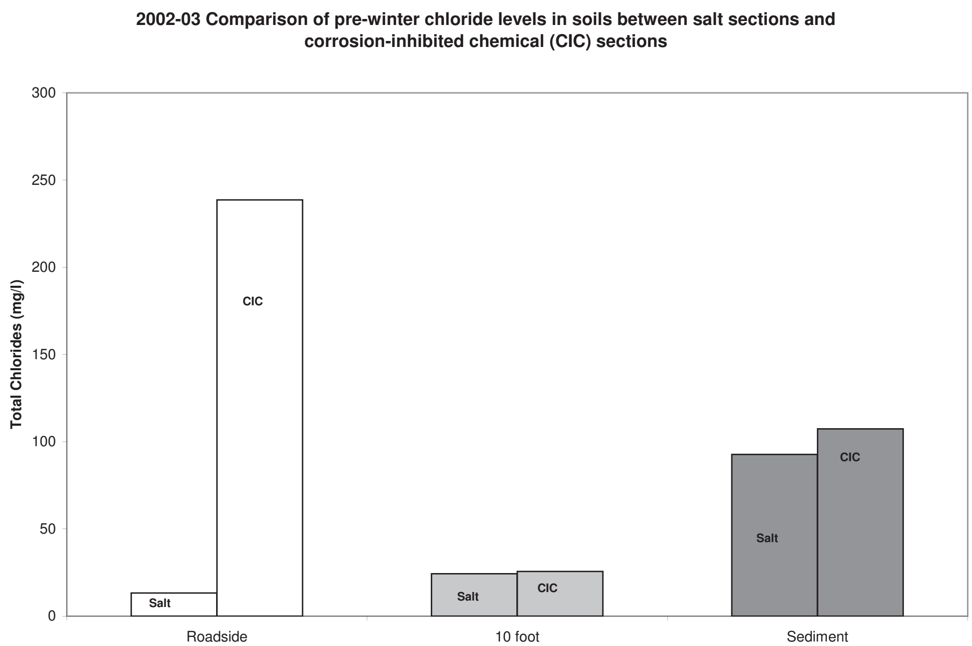


Figure 19: Pre-winter Chloride Levels in Soils

The next chart shows a similar comparison of chloride levels after the end of the winter season. Each column represents the average of all post-winter samples taken at each location. Chloride levels in soils do not appear to follow a pattern of more or less presence depending on whether salt was used or corrosion-inhibited chemicals were used. Overall levels of chlorides are relatively low falling well below levels that would generate concern related to environmental or health protection. No significant increase in chloride levels occurred at the sample locations as a result of a winter's worth of chemical applications.

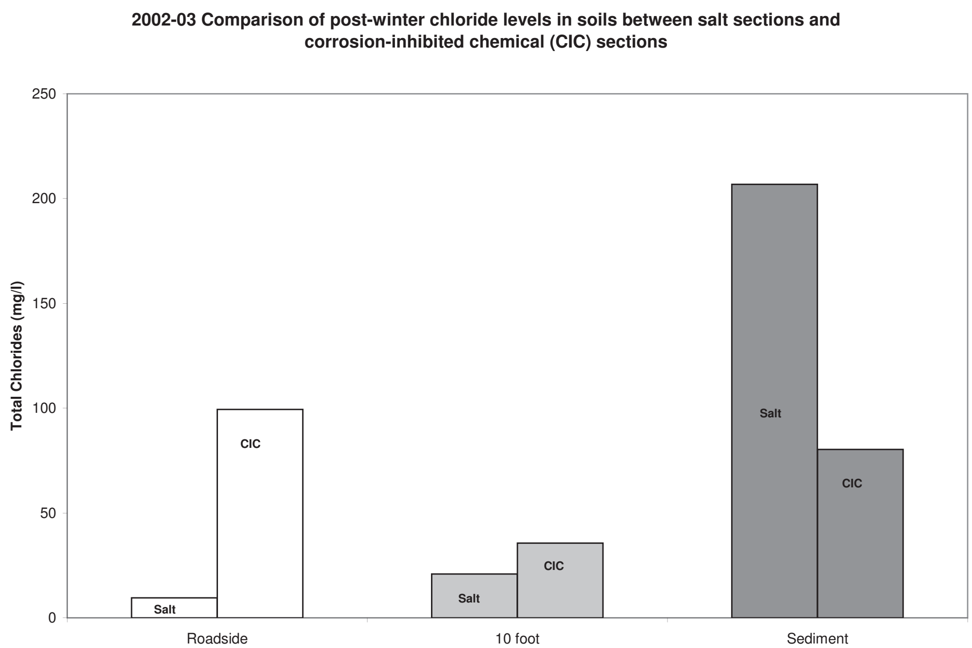
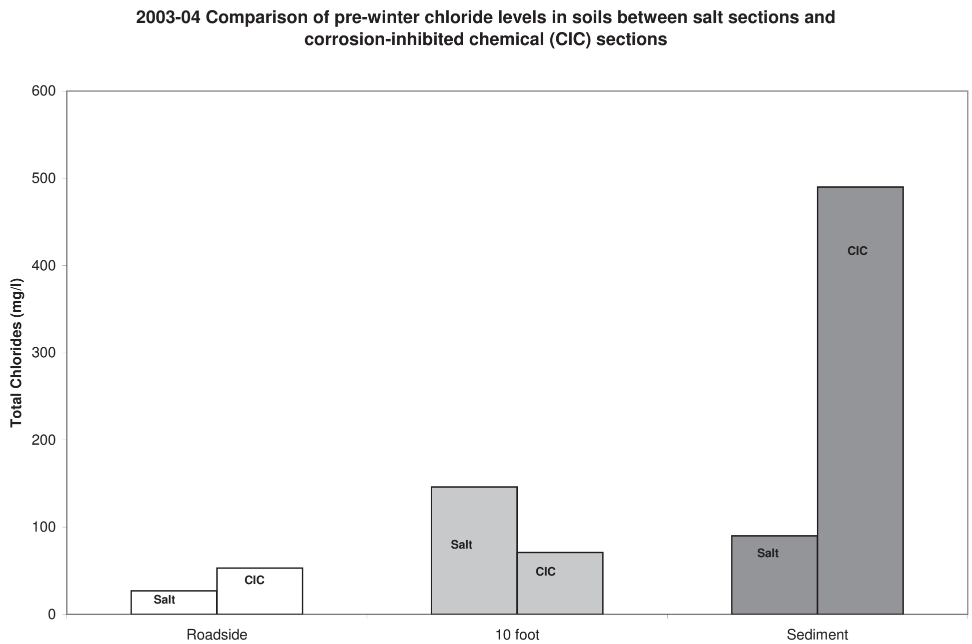


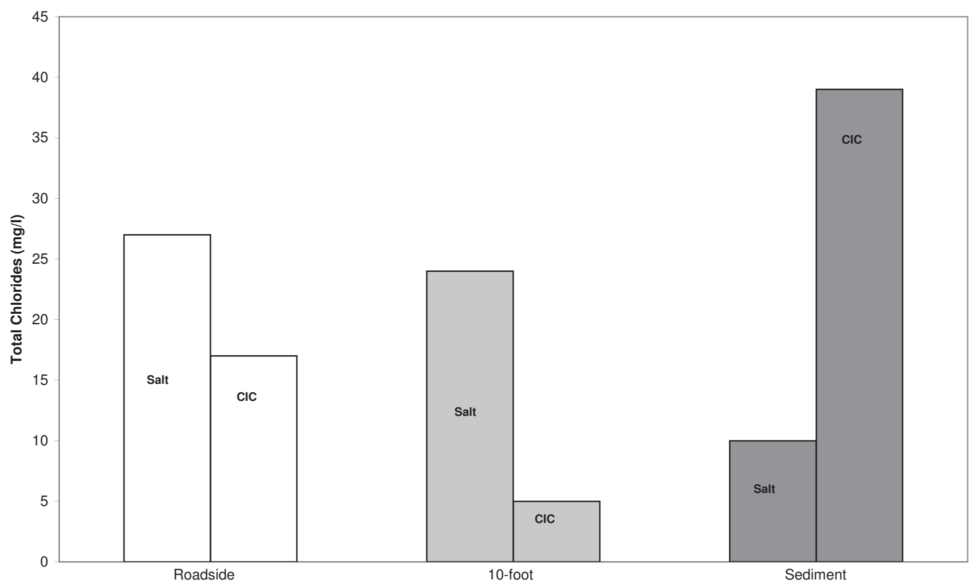
Figure 20: Post-winter Chloride Levels in Soils

The following chart shows comparisons of chloride levels in soils in the salt sections and the corrosion-inhibited chemical sections before the 2003-04 winter season commenced. Each column represents the average of all pre-winter samples taken at each location. Overall levels of chlorides are relatively low falling well below levels that would generate concern related to environmental or health protection.



The next chart shows a similar comparison of chloride levels after the end of the winter season. Each column represents the average of all post-winter samples taken at each location. Chloride levels in soils do not appear to follow a pattern of more or less presence depending on whether salt was used or corrosion-inhibited chemicals were used. Overall levels of chlorides are relatively low falling well below levels that would generate concern related to environmental or health protection. No significant increase in chloride levels occurred at the sample locations as a result of a winter's worth of chemical applications.

2003-04 Comparison of post-winter chloride levels in soils between salt sections and corrosion-inhibited (CIC) chemical sections



Water Chlorides Comparisons – Salt Sections and Corrosion-inhibited Chemical Section

The next chart shows a comparison of chloride levels in surface water and drinking water between the salt sections and corrosion-inhibited chemical sections before the 2002-03 winter season commenced. Each column represents the average of all pre-winter samples taken at each location. Chloride levels in both surface waters and drinking waters in the salt section were significantly higher than in the corrosion-inhibited chemicals section.

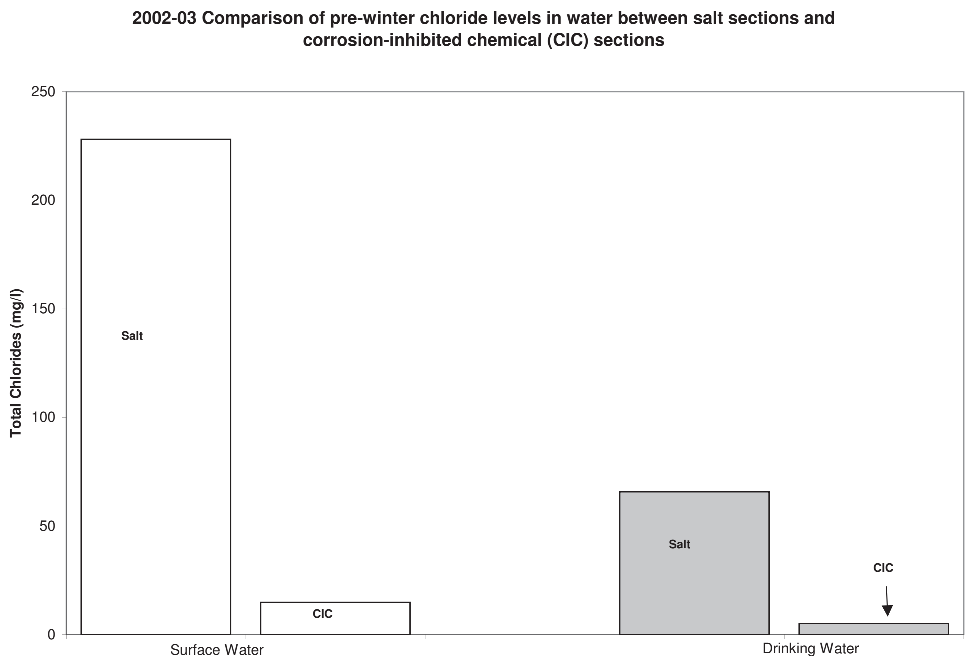


Figure 21: Pre-winter Chloride Levels in Water

The next chart shows a similar comparison of chloride levels after the end of the winter season. The comparative levels of chlorides in surface and drinking water in the salt and corrosion-inhibited chemical sections are very similar to the pre-winter levels. Chloride levels are relatively low compared to related water quality guidelines and other, related reference levels. Chloride levels measured in the control (background) areas were significantly lower than roadside areas for both sodium chloride and corrosion-inhibited chemicals.

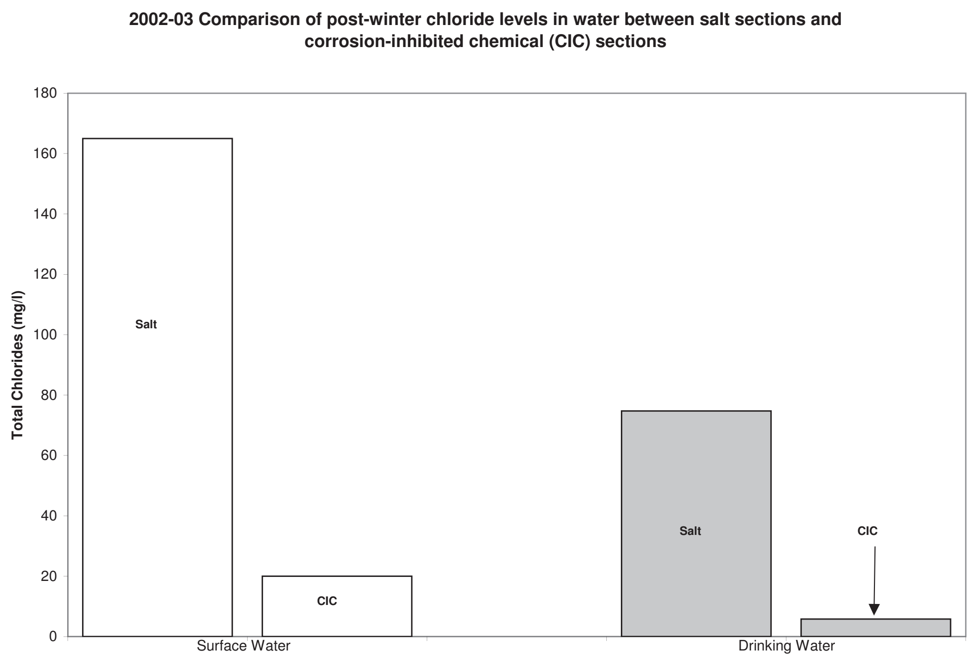
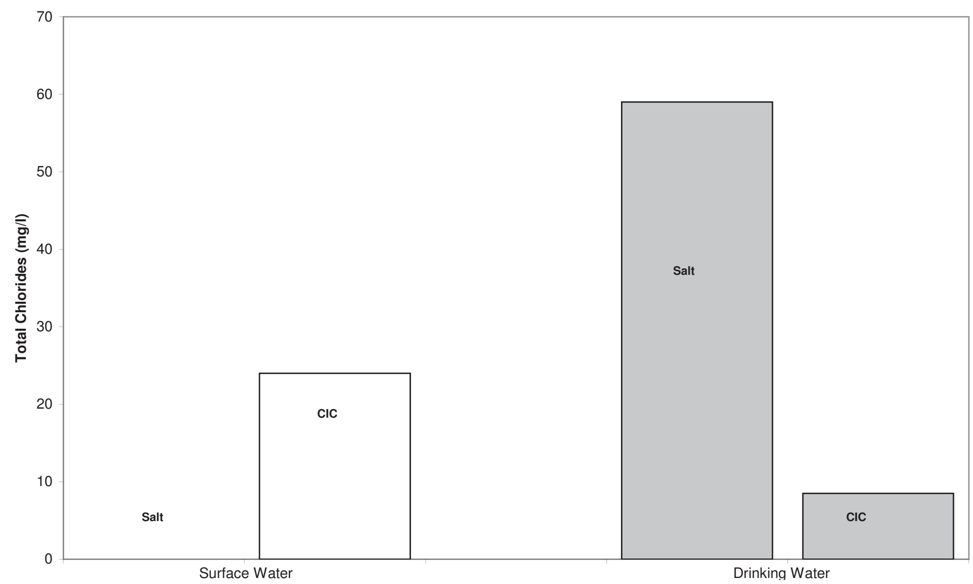


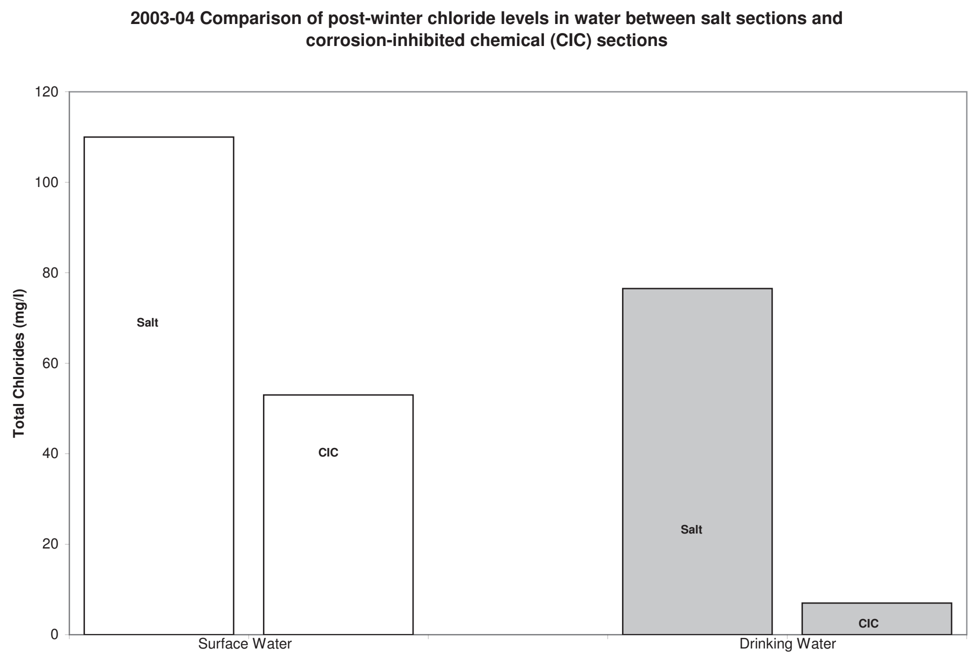
Figure 22: Post-winter Chloride Levels in Water

The next chart shows a comparison of chloride levels in surface water and drinking water between the salt sections and corrosion-inhibited chemical sections before the 2003-04 winter season commenced. Each column represents the average of all pre-winter samples taken at each location. No data is represented for surface water in the salt sections as no surface water was present at the time of sampling.

2003-04 Comparison of pre-winter chloride levels in water between salt sections and corrosion-inhibited chemical (CIC) sections



The next chart shows a similar comparison of chloride levels after the end of the winter season. The comparative levels of chlorides in surface and drinking water in the salt and corrosion-inhibited chemical sections are very similar to the pre-winter levels. Chloride levels are relatively low compared to related water quality guidelines and other, related reference levels. Chloride levels measured in the control (background) areas were significantly lower than roadside areas for both sodium chloride and corrosion-inhibited chemicals.



Discussion

The chloride levels in water are consistently higher in the salt sections than in the corrosion inhibited chemical sections but this appears to be related more to background levels rather than resultant of chemical applications during the evaluation. Overall, the information indicates that WSDOT's application of de-icing chemicals, either corrosion inhibited or sodium chloride, is not resulting in chloride levels that are above any state or federal standard or guideline.

The drinking water data indicates little to no influence on chloride levels from the anti-icing operation. No significant differences in chloride levels were identified at the end of winter compared to before winter. Since no mid-winter snowmelt events were measured, it is unknown if short-term changes in chloride levels occurred during winter. Once winter set in, temperatures never rose significantly enough to result in a snowmelt event until the end of winter. Control areas show that they have not been affected by chloride applications and are indeed control areas. In general, the winter of 2002-03 was mild and atypical from a snow and ice maintenance standpoint. As a result, significantly less anti-icing agents were applied to the roadway. While the winter of 2003-04 was more of an "average" winter with more resultant chemical use, the data did not show significant changes in environmental chloride levels.

Project Findings

In eastern Washington, the operational costs per lane mile of using salt brine and rock salt were not significantly and consistently different from the costs of using corrosion-inhibited chemicals in comparable sections. During the winter of 2002-03, which was milder than average, the costs per lane mile were as much as 37 percent lower in the salt sections. During the winter of 2003-04, which was more of an average winter, costs per lane mile for salt use ranged from 3 percent less to 10 percent more compared to the adjacent corrosion-inhibited chemical section. After further discussion and analysis, several factors contributed to the salt costs per lane mile being higher than expected.

- The cost to purchase rock salt in Washington State was higher than what other state DOTs typically incur. One factor leading to this is that there are no salt mines close to Washington so transportation costs are higher than for other parts of the country. WSDOT's chemical contract has some strict requirements (i.e., short delivery times after orders are placed) that may have increased prices.
- Effective application rates for salt brine are higher than for the corrosion-inhibited chemicals. Salt brine is typically applied at rates of 45-50 gallons per lane mile. Corrosion-inhibited $CaCl_2$ is typically applied at rates of 15-35 gallons per lane mile.

- The sections using corrosion-inhibited $CaCl_2$, applied the liquids with a single, 6,000-gallon truck. With the lower application rates used for $CaCl_2$, one driver and one truck could cover the entire test section in one trip. In the adjacent sections using salt brine, two smaller trucks were used to apply the liquids. With the higher application rates used for salt brine, two drivers and two trucks would leave the maintenance yard to apply salt brine. They would shortly empty the trucks, have to return to refill with more salt brine then drive further out to continue their applications. For a single application on the entire salt test section, the multiple "back and forth" trips of two drivers and two trucks increased the costs of the salt brine operation. These increased labor and equipment expenses offset savings from the use of the less expensive (per gallon) salt brine.

Use of a factory-built brine maker turned out to be a cost-effective method of supplying maintenance crews with salt brine. Once the maintenance crew at Ritzville learned how to use the brinemaker, they found it very easy to work with and reliable. Alternatively, the Southwest Region found that hand mixing salt using bagged salt was not cost-effective. The per ton cost of salt was much higher when purchased in bags compared to when purchased in bulk. Hand mixing was very labor intensive. These higher costs resulted in per gallon salt brine costs being similar to the costs of corrosion inhibited liquids.

The general performance of salt was found to be similar to the corrosion-inhibited chemicals tested. The maintenance crews using salt were able to deliver a Level of Service comparable to that delivered by crews using corrosion-inhibited chemicals. The primary limitation of salt is the relatively limited temperature range in which it will work. This has not been a major obstacle to delivering a high Level of Service in the test sections.

This evaluation indicates that significantly different corrosion processes, related to the use of roadway snow and ice control chemicals, occur in various comparison scenarios.

In eastern Washington, exposure of the steel coupons mounted underneath maintenance trucks and supervisor trucks to corrosion-inhibited chemicals consistently resulted in less corrosion than similar coupons exposed to salt. In other words, the benefit of reduced corrosion to steel in motor vehicles was realized by the use of corrosion-inhibited chemicals. While these levels of reduced corrosion did not generally meet the specification of "70 percent less corrosive than salt," the level of reduced corrosion was significant. The most significant reductions in corrosion were experienced in the section that used the liquid calcium chloride product.

In western Washington, the levels of reduced corrosion to steel coupons mounted on maintenance trucks and exposed to corrosion-inhibited chemicals (compared to the exposure to salt) were not seen as they were in eastern Washington. In the first winter season, there was slightly less corrosion from exposure to corrosion-inhibited chemicals than the coupons exposed to salt. In the second winter season, there was more corrosion from exposure to corrosion-inhibited chemicals than there was from exposure to salt. The benefits of reduced corrosion to steel in motor vehicles that was realized in eastern Washington, was not apparent in the limited data from the test section in western Washington. Supervisor trucks were not used as part of the evaluation in western Washington due to the small test section used.

In all eastern Washington test sections, steel coupons were mounted on guardrail posts. At these locations, corrosion rates were consistently higher in those coupons exposed to corrosion-inhibited chemicals compared to coupons exposed to salt. There is no direct relationship between measured corrosion to a steel coupon on the roadside and projected corrosion to steel in a bridge deck, in concrete pavement, or within a bridge structure. The significant difference between corrosion to steel in motor vehicles on the roadway and steel on the roadside certainly raises the question of different corrosion rates or processes when steel bridge structures and/or steel rebar is exposed to snow and ice control chemicals. A full guardrail-mounted coupon comparison was not included as part of the evaluation in western Washington due to the small test section used.

Corrosion rates to the aluminum coupons were varied. In some cases, there was less corrosion from salt exposure than corrosion-inhibited chemical exposure and vice versa in other cases. It is not known whether majority of aluminum corrosion is caused by the chloride compound itself or the corrosion-inhibiting additive. The total amount of corrosion weight loss on the steel coupons is much greater than the total amount of corrosion weight loss on the aluminum coupons. The corrosion on the steel coupons takes the form of a uniform layer of rust. In more severe cases of corrosion, this will result in layers of rust and metal scaling from the surface. The corrosion in aluminum takes the form of pitting on the surface. For items such as cast aluminum wheels, this is primarily an aesthetic issue as opposed to a structural or safety issue. However, there are several automotive components in which severe pitting can adversely affect the safety of an automobile's use. The different types of corrosion are evident when measuring corrosion in terms of weight loss. Corrosion to steel is measured in terms of grams. Corrosion to aluminum is measured in terms of tenths of grams.

The focus of the development of the PNS corrosion specification was on corrosion to steel. The project findings indicate the specification is not particularly suitable to address impacts to sheet and cast aluminum. The percentage of the total weight of the aluminum coupon that is lost to corrosion (see table below) is so small that conclusions are not as firm as those drawn from steel corrosion data. Perhaps a test that would measure loss of strength or pitting/surface deformation would be a better way to test for aluminum corrosion.

Percentage of Beginning Coupon Weight Lost to Corrosion – 2003-04 South Central Region Salt Section

Steel	8.33%
Sheet Aluminum	0.28%
Cast Aluminum	0.07%

The project findings show some interesting variations in corrosion rates from the use of corrosion-inhibited chemicals. The chemicals meet, or come close to meeting, the corrosion specification when they are delivered to WSDOT maintenance yards. The chemicals' effectiveness (related to reduced corrosion) appears to be reduced after they are applied to the roadway and motor vehicles are exposed to them. As the chemicals are splashed off the roadway or otherwise migrate to the roadside, the findings indicate some significant changes in corrosion rates. In some cases, corrosion rates on the guardrail-mounted coupons were less than on the truck-mounted coupons. In other cases, corrosion rates were more than twice as high at the guardrail location than they were on trucks. This could have significant ramifications to corrosion issues related to bridges, steel re-bar in concrete pavement, and other metal-containing highway features. This is an area on which additional research should focus.

In evaluating corrosion costs, the evaluation does not provide enough information for a definitive comparison. While the use of corrosion-inhibited chemicals appears to reduce corrosion (and hence some level of potential, eventual cost savings) of steel in motor vehicles, the findings indicate the possibility of less corrosion reduction (and hence some level of potential, eventual cost increases) as chemicals move from the roadway to the roadside. Also, while the use of corrosion-inhibited chemicals appears to reduce corrosion costs related to steel, it appears to increase corrosion related to aluminum in some cases. Some costs would also be associated with these impacts.

In evaluating environmental impacts, there appears to be little to no difference in impacts between salt use and the use of corrosion-inhibited chemicals. They both are applied in a similar fashion and they both contain comparable levels of chlorides.

Recommended Actions

This evaluation highlights some very important issues. Related policy decisions should be made only after a thorough analysis of related data and comprehensive discussions of costs and benefits. This evaluation provides limited data to support such decisions and represents the first of many steps in that direction.

There are many aspects of this evaluation that could be further refined through more formal research methods. This would diversify and build upon the information gained from this project. For example, a research project could identify the variables both on and off the roadway environment that impact corrosion. These variables could then be more closely managed during an evaluation to strengthen the accuracy of the data.

Policy decisions regarding the use of salt or corrosion-inhibited chemicals should be made in the context of asset management rather than the narrower focus of operations management. Immediate costs/savings related of using certain snow and ice control chemicals and costs/savings related to improved motorist safety/mobility need to be balanced with the longer-term costs/savings such as those of corrosion to motor vehicles and the preservation of bridges and pavements.

The corrosion data focuses on how field performance of the corrosion-inhibited chemicals relates to the chemical's laboratory performance. Additional research should be conducted to help identify corrosion rates to different metals that are acceptable to highway asset managers and the motoring public. In other words, what levels of corrosion can we live with to get the safety and mobility benefits that the use of snow and ice control chemicals provides?

The currently used corrosion specification and related laboratory procedures should be re-evaluated to identify ways to improve its relationship to actual corrosion rates.

Appendix 1

2002-03 Snow and Ice Control Level of Service (LOS) Data

TEST (SALT) SECTIONS

LOCATION	SR	MILEPOST	SITE #	NUMBER OF COMPLETED SURVEYS	AVG. LOS RATING	LETTER GRADE EQUIVALENT
SC Test (Salt)	90	120-122	522	14	1.5	A
	90	125-127	523	15	1.4	A
Section LOS					**1.5**	**A**
Eas. Test (Salt)	90	237-239	614	16	1.3	A
Section LOS					**1.3**	**A**
SW Test (Salt)	6	10-12	421	5	1.9	A-
	6	21-23	438	5	1.9	A-
	6	31-33	437	5	1.8	A-
Section LOS					**1.9**	**A-**

CONTROL (CORROSION-INHIBITED CHEMICALS) SECTIONS

LOCATION	SR	MILEPOST	SITE #	NUMBER OF COMPLETED SURVEYS	AVG. LOS RATING	LETTER GRADE EQUIVALENT
NC Control (Corrosion-Inhibited Chemicals	90	152-154	211	6	1.0	A+
	90	182-184	216	3	1.0	A+
Section LOS					**1.0**	**A+**
Eas. Control (Corrosion-inhibited Chemicals)	90	268-270	621	5	1.1	A+
	90	278-280	602	5	1.8	A-
	90	290-292	622	2	1.0	A+
Section LOS					**1.3**	**A**
SW Control (Corrosion-inhibited Chemicals)	508	10-12	412	2	3.5	C
	101	39-41	422	4	1.5	A
	101	65-67	423	7	2.4	B
	105	4-6	424	3	3.0	C+
Section LOS					**2.6**	**B**

Appendix 2

2003-04 Snow and Ice Control Level of Service (LOS) Data

TEST (SALT) SECTIONS

LOCATION	SR	MILEPOST	SITE #	NUMBER OF COMPLETED SURVEYS	AVG. LOS RATING	LETTER GRADE EQUIVALENT
SC Test (Salt)	90	120-122	522	5	1.4	A
	90	125-127	523	5	1.5	A
Section LOS					**1.5**	**A**
Eas. Test (Salt)	90	237-239	614	6	1.1	A+
	90	206-208	623	7	1.1	A+
Section LOS						**A+**
SW Test (Salt)	6	10-12	421	7	2.3	B
Section LOS					**2.3**	**B**

CONTROL (CORROSION-INHIBITED CHEMICALS) SECTIONS

LOCATION	SR	MILEPOST	SITE #	NUMBER OF COMPLETED SURVEYS	AVG. LOS RATING	LETTER GRADE EQUIVALENT
NC Control (Corrosion-Inhibited Chemicals	90	152-154	211	2	1.0	A+
Section LOS					**1.0**	**A+**
Eas. Control (Corrosion-inhibited Chemicals)	90	268-270	621	16	2.0	B+
	90	278-280	602	1	1.0	A+
	90	290-292	622	4	1.0	A+
Section LOS					**1.8**	**A-**
SW Control (Corrosion-inhibited Chemicals)	508	10-12	412	6	1.8	A-
	101	39-41	422	7	2.2	B+
	101	65-67	423	7	2.4	B
	105	4-6	424	6	3.3	C
Section LOS					**2.4**	**B**

Appendix 3 Laboratory Procedure for Corrosion Testing

(WSDOT Test Method T 418)

1. SCOPE

   The weight loss of steel coupons subjected to corrosion by deicing salts for a given period of time is determined. This weight loss is converted to mils penetration per year of the steel surface by the deicing salt. The ratio of the deicing salt sample to a sodium chloride control sample is reported to provide a means to evaluate and compare the corrosion rates of different deicing salts. (This procedure is a modification of NACE Standard TM-01-69 (1976 Revision)).

2. APPARATUS

   a. Timer, adjustable, that can be set for a 50 minute (up position) and a 10 minute (down position) cycle every hour, and able to cycle for 72 hours.

   b. Immersion testing device capable of automatically subjecting the coupons to an immersion/no immersion cycle. A device with a bar, configured like a crank to which a line from the coupon holder is attached, with an electric motor, governed by the timer, that cycles the crank up and down, is one type of tester.

   c. 500 Erlenmeyer flasks fitted with one-hole rubber stoppers, one flask for each sample plus one for a distilled water control and one for a sodium chloride standard.

   d. Non-corrosive (e.g., polyethylene) coupon holders attached to the immersion testing device with non-corrosive line (e.g., polypropylene fish line). Each coupon holder to hold three coupons.

   e. Coupons, non-galvanized 1/2 in. (13 mm) flat steel washers having the approximate dimensions of 1.38 in. (35 mm) outside diameter by 0.56 in. (14 mm) inside diameter by 0.12 in. (3 mm) thick. Coupons must meet ASTM F436, Type 1, with a Rockwell Hardness of C 38-45. Three coupons are needed for each sample.

   f. Polypropylene bottlers, for sample dissolution, one for each sample.

   g. Balance, accurate to 0.0001 g.

   h. Metal stamp numbering set.

   i. Dial Caliper to measure coupons, accurate to 0.01 mm.

3. REAGENTS

   a. Hydrochloric Acid cleaning solution. Make by dissolving 50 g $SnCl_2$ (stannous chloride) and 20 g $SbCl_3$ (antimony trichloride) in 1000 ml of concentrated Hydrochloric Acid.

   b. Distilled water conforming to ASTM D 1193 Type II.

   c. Chloroform, technical grade.

   d. Acetone, technical grade.

   e. Sodium Chloride standard. Make a 3 percent by weight solution of reagent grade Sodium Chloride in distilled water.

   f. Hydrochloric Acid, 1 + 1.

4. PREPARATION OF THE COUPONS

   a. Wipe each coupon with a suitable solvent to remove grease and oil.

   b. Examine each coupon for metallurgical abnormalities and reject those that are suspect to flaws.

   c. Acceptable coupons are stamped for identification.

   d. Coupons are acid etched with 1+1 HCl for approximately 2-3 minutes.

   e. The coupons are quickly rinsed with tap water, then distilled water, wiped dry and placed in chloroform.

   f. When the coupons are removed from the chloroform for use, they are placed on a paper-lined tray (not touching each other) and allowed to air dry in a ventilated hood for a minimum of 15 minutes.

   g. Coupons are measured as specified in Section 5. (Note: If latex gloves are not worn during measuring, the coupons should be rinsed again and dried as prescribed above prior to _weighing. This will remove any oils that may be transferred to the coupons.)

   h. Each coupon shall be weighed to a constant weight. The constant weight is obtained when two consecutive weighings of each coupon are within a minimum of 0.5 milligrams of each other. Removal of incidental flash rusting prior to weighing is not necessary.

   i. Three coupons are used in each chemical product solution and for the distilled water and Sodium Chloride controls.

5. MEASURING THE COUPONS

   The outside diameter, inside diameter, and the thickness of each coupon is measured twice at 90 degrees from each initial reading and the averages calculated for each measurement. The _averages are than used to calculate the surface area of each coupon with the following formula:

A = (3.1416/2)(D2-d2) + 3.1416(t)(D) + 3.1416(t)(d)

Where D = average outside diameter
d = average inside diameter
t = average thickness

6. SAMPLE PREPARATION

Make a 3 percent by weight solution of each deicing salt by weighing 30.00 g (as received) of the sample and dissolving in 970.00 g of distilled water. Allow the solutions to sit a minimum of 12 hours in polyethylene bottles to insure maximum solubility and to allow for any reactivity (i.e., heat of hydration and heat of solution).

7. PROCEDURE

Approximately 300 milliliters of the deicing solution as mixed with distilled water is placed into a 500 ml Erlenmeyer flask. Each flask is equipped with a rubber stopper that has been drilled to allow a line to run through it. One end of the line is attached to a rotating bar and the other end of the line is attached to a plastic frame made to hold the three coupons inside the flask. The rotating bar is controlled by an electric timer that lowers the coupon holding apparatus into the solution for 10 minutes then raises the coupon holding apparatus out of the solution for 50 minutes but still keeps the coupons inside of the flask for the entire duration of the test. The corrosion test is run for 72 hours. No agitation of the solution is made during the corrosion test.

Corrosion tests are conducted at normal room temperature. The room temperature is to be recorded daily during the operation of the test. The room temperature shall be taken with a calibrated thermometer located next to the corrosion-testing instrument.

8. CLEANING OF THE COUPONS

The coupons are removed from the solution after 72 hours. They are placed in glass beakers containing the Hydrochloric Acid cleaning solution. (Note: The fumes given off by the acid during cleaning contain gases formed from the antimony and are extremely hazardous, this portion of the cleaning must be conducted under a fume hood).

After 15 minutes of cleaning the coupons are removed from the cleaning acid, rinsed with tap water, then distilled water, and wiped with a cloth to clean any deposits from the coupons. They are then returned to the cleaning acid and the procedure is repeated. After cleaning, the coupons are rinsed in chloroform, air-dried, and weighed.

Each coupon shall be weighed to a constant weight. Constant weight is obtained when two consecutive weighings of each coupon are within a minimum of 0.5 milligrams of each other.

9. EVALUATION OF CORROSION

The weight loss of each coupon is determined by subtracting the final weight from the original weight. The corrosion rate for each coupon is expressed as mils penetration per year (MPY) by the following formula:

MPY = [(weight loss (milligrams)](534)/[(area)(time)(metal density*)]

* metal density for steel is 7.85 g/cc

The final MPY value for each solution is determined by calculating an average of the three individual coupons. (Note: Wide variation of MPY of individual coupons inside the same flask typically indicates contamination of a coupon. If variation of individual MPY is too great to _determine consistent data the test should be repeated. Typically coupon variation may run plus or minus 3 MPY).

10. REPORTING RESULTS

Results shall be reported in Percent Effectiveness (also referred to as "Percent as Corrosive as NaCl"). Results equal to or less than 30 percent are passing.

The MPY is determined as above for the deicing salt samples, the distilled water blank and for the sodium chloride standard.

The MPY determined for the distilled water blank is subtracted from the MPY value obtained for the deicing samples to arrive at an adjusted deicing sample MPY. Likewise, the distilled water blank is subtracted from the MPY value of the sodium chloride standard to obtain the adjusted NaCl standard MPY.

The adjusted deicing sample MPY is divided by the adjusted NaCl standard MPY and multiplied by 100 to obtain the corrosion of the sample as a percent of the sodium chloride corrosion result.

% Effectiveness = [adjusted deicing sample MPY/adjusted NaCl standard MPY] x 100

(All weight measures are in grams)

2002-03 SALT PILOT PROJECT-CORROSION DATA

SOUTH CENTRAL REGION - SALT/TEST SECTION

		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet 5182			Cast Aluminum A356		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1	8E12-9	2366	2575	209	48177	53529	5352	1A	96.883	92.452	4.431	41.046	40.992	0.054	254.512	254.341	0.171
								1B	97.112	93.070	4.042	41.286	41.235	0.051	255.397	255.228	0.169
2	6E13-1	7931	8171	240	201842	208035	6193	2A	96.886	90.076	6.810	41.086	41.051	0.035	263.851	263.600	0.251
								2B	97.342	90.779	6.563	41.311	41.268	0.043	250.509	250.302	0.207
Average Weight Loss - Maintenance Trucks											**5.462**			**0.046**			**0.199**
Baseline											1.638			0.014			0.060
3	5E20-7				71876	78657	6781	3A	96.482	89.062	7.420	41.065	40.919	0.146	248.963	248.749	0.214
								3B	96.753	89.182	7.571	41.278	41.126	0.152	248.846	248.680	0.166
Average Weight Loss - Supervisor Truck											**7.496**			**0.149**			**0.190**
Remote									**missing**	**missing**	**missing**	**missing**	**missing**	**missing**	**missing**	**missing**	**missing**
Roadside									97.518	91.212	**6.306**	41.412	41.386	**0.026**	254.277	254.208	**0.069**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

2002-03 SALT PILOT PROJECT-CORROSION DATA

NORTH CENTRAL REGION - CORROSION-INHIBITED CHEMICAL/CONTROL SECTION

		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet A562			Cast Aluminum		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1								1A	96.688								
								1B	97.243								
2	6B13-49	370	518	148	11013	15909	4896	2A	97.025	93.938	3.087	41.507	41.477	0.030	256.195	255.980	0.215
								2B	97.796	94.911	2.885	41.816	41.794	0.022	257.416	257.336	0.080
3	19B8-3	1607			27765			3A	97.376	95.128	2.248	41.706	41.496	0.210	264.473	264.282	0.191
								3B	97.482	95.481	2.001	41.493	41.193	0.300	259.653	259.522	0.131
Average Weight Loss - Maintenance Trucks											**2.555**			**0.141**			**0.154**
7	5B10-32							7A	97.428	94.374	3.054	41.244	41.073	0.171	256.163	256.044	0.119
								7B	97.728	94.719	3.009	41.420	41.248	0.172	263.090	262.950	0.140
Average Weight Loss - Supervisor Truck											**3.032**			**0.172**			**0.130**
Remote (background) baseline									96.227	95.350	**0.877**	41.266	41.261	**0.005**	257.071	257.046	**0.025**
Roadside									96.783	89.428	**7.355**	41.266	41.205	**0.061**	255.759	255.588	**0.171**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

2002-03 SALT PILOT PROJECT-CORROSION DATA

EASTERN REGION (AREA 3) - SALT/TEST SECTION

		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet A562			Cast Aluminum		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1	6G13-44	3521	3727	206	104676	111150	6474	1A	96.905	85.926	10.979	40.971	40.763	0.208	252.486	252.170	0.316
								1B	96.897	86.278	10.619	41.257	40.962	0.295	246.980	246.803	0.177
2	8G13-02	741	959	218	18601	24202	5601	2A	96.611	91.044	5.567	40.948	40.920	0.028	256.784	256.468	0.316
								2B	97.111	92.502	4.609	41.127	41.090	0.037	251.407	251.147	0.260
3	6B13-43	2782	2941	159	83700	88437	4737	3A	96.490	86.305	10.185	40.680	40.368	0.312	252.668	252.420	0.248
								3B	96.518	85.460	11.058	41.167	40.820	0.347	260.157	259.907	0.250
4	6G13-70	1222	1345	123	26239	28991	2752	4A	96.286	88.450	7.836	40.909	40.824	0.085	259.964	259.757	0.207
								4B	97.548	88.927	8.621	41.090	41.006	0.084	243.874	243.747	0.127
5	6G6-95							5A	96.656	88.314	8.342	40.994	40.875	0.119	243.425	243.272	0.153
								5B	97.560	88.694	8.866	41.214	41.037	0.177	252.697	252.516	0.181
6	6G13-84	70	96	26	3035	3707	672	6A	96.952	91.942	5.010	41.072	41.028	0.044	246.432	246.290	0.142
								6B	96.862	91.849	5.013	41.005	40.932	0.073	243.390	243.241	0.149
7	6G13-47	2073	2201	128	44581	47561	2980	7A	96.742	87.082	9.660	40.954	40.847	0.107	256.058	255.824	0.234
								7B	96.572	88.048	8.524	41.149	40.997	0.152	251.411	251.170	0.241
8	6G13-38	3339	3536	197	104112	110045	5933	8A	96.534	81.807	14.727	41.031	40.648	0.383	252.902	252.610	0.292
								8B	96.788	78.274	18.514	41.148	40.896	0.252	253.824	253.488	0.336
9	8G29-2				108192	109788	1596	9A	95.982	93.260	2.722	40.947	40.922	0.025	260.489	260.384	0.105
								9B	96.854	93.755	3.099	41.317	41.280	0.037	256.980	256.870	0.110
Average Weight Loss - Maintenance Trucks											**8.553**			**0.154**			**0.214**
10	5E20-44							10A	96.215	88.102	8.113	40.964	40.833	0.131	252.745	252.608	0.137
								10B	97.083	88.791	8.292	41.169	41.033	0.136	249.102	248.946	0.156
Average Weight Loss - Supervisor Truck											**8.203**			**0.133**			**0.147**
Remote									95.931	95.557	**0.374**	40.832	40.830	**0.002**	265.098	265.083	**0.015**
Roadside									97.404	91.043	**6.361**	41.188	41.153	**0.035**	262.917	262.748	**0.169**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

2002-03 SALT PILOT PROJECT-CORROSION DATA

EASTERN REGION (AREA 1) - CORROSION-INHIBITED CHEMICAL/CONTROL SECTION

		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet A562			Cast Aluminum		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1	8B12-8	3228	3484	256	58483	63595	5112	1A	97.377	87.524	9.853	41.480	41.224	0.256	255.458	255.034	0.424
								1B	97.188	87.594	9.594	41.677	41.414	0.263	258.660	258.138	0.522
2	6G13-39	4145	4315	170	93631	96907	3276	2A	97.076	92.184	4.892	41.550	41.350	0.200	254.994	254.836	0.158
								2B	97.110	90.912	6.198	41.747	41.545	0.202	255.785	255.582	0.203
3	6G6-3	2772	2855	83	57481	59417	1936	3A	96.633	90.941	5.692	41.559	40.938	0.621	254.838	254.685	0.153
								3B	96.511	88.929	7.582	41.824	41.340	0.484	256.156	255.972	0.184
4	6G13-71	2463	2696	233	57985	63234	5249	4A	96.470	87.758	8.712	41.636	41.376	0.260	255.896	255.694	0.202
								4B	96.971	87.727	9.244	41.797	41.636	0.161	255.061	254.870	0.191
5	6G13-79	287	374	87	6115	7866	1751	5A	97.446	93.775	3.671	41.505	41.428	0.077	254.545	254.356	0.189
								5B	97.369	92.246	5.123	41.728	41.668	0.060	257.031	256.879	0.152
6	6G13-40	4074	4238	164	95401	99073	3672	6A	96.691	91.819	4.872	41.219	41.129	0.090	254.723	254.572	0.151
								6B	97.403	92.208	5.195	41.398	41.299	0.099	263.903	263.764	0.139
7	6G13-63	1685	1847	162	39267	42865	3598	7A	96.976	91.171	5.805	41.189	40.477	0.712	254.858	254.614	0.244
								7B	96.833	92.245	4.588	41.449	41.045	0.404	254.239	253.943	0.296
8	8G12-11	3270	3367	97	84676	86638	1962	8A	96.810	91.978	4.832	41.483	41.218	0.265	256.078	255.840	0.238
								8B	96.771	91.564	5.207	41.422	41.144	0.278	249.664	249.465	0.199
9	6G13-76	958	1197	239	21090	26183	5093	9A	96.510	93.737	2.773	41.346	39.838	1.508	252.722	252.406	0.316
								9B	97.286	91.900	5.386	41.400	40.250	1.150	254.107	253.846	0.261
10	8G12-7	1993	2165	172	28706	31511	2805	10A	96.578	91.050	5.528	41.344	41.248	0.096	254.834	254.600	0.234
								10B	96.775	91.546	5.229	41.201	41.112	0.089	257.881	257.646	0.235
Average Weight Loss - Maintenance Trucks											**5.999**			**0.364**			**0.235**
11	5G20-40							11A	97.233	91.296	5.937	41.297	41.183	0.114	255.914	255.786	0.128
								11B	97.001	90.986	6.015	41.390	41.284	0.106	257.119	256.984	0.135
Average Weight Loss - Supervisor Pickup Truck											**5.997**			**0.342**			**0.226**
Remote									96.371	95.783	**0.588**	41.006	41.002	**0.004**	260.442	260.390	**0.052**
Roadside									97.695	90.741	**6.954**	41.217	41.196	**0.021**	254.819	254.728	**0.091**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

2002-03 SALT PILOT PROJECT-CORROSION DATA

SOUTHWEST REGION - SALT/TEST SECTION

		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet A562			Cast Aluminum		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
2	8D29-4							3A	97.610	93.921	3.689	41.477	41.442	0.035	254.312	254.186	0.126
								3B	98.653	93.860	4.793	41.728	41.680	0.048	264.843	264.722	0.121
3	6D6-95							4A	97.280	90.246	7.034	41.507	41.390	0.117	254.035	253.652	0.383
								4B	98.063	88.234	9.829	41.782	41.629	0.153	254.803	254.398	0.405
Average Weight Loss - Maintenance Trucks											**6.336**			**0.088**			**0.259**
Remote - 150' off HWY 6 MP 25									97.797	97.326	0.471	41.617	41.608	0.009	243.354	243.305	0.049
Remote - Hope Creek Pit - 200' off HWY 6									97.331	96.774	0.557	41.397	41.388	0.009	254.060	254.102	-0.042
Average Weight Loss - Remote Locations											**0.343**			**0.009**			**0.004**
Guard Rail Post Hwy 6									98.422	95.536	2.886	41.734	41.718	0.016	262.672	262.565	0.107
Sign Post HWY 6 MP 46									98.606	94.169	4.437	41.738	41.708	0.030	263.948	263.823	0.125
Average Weight Loss - Roadside Locations											**3.662**			**0.023**			**0.116**
Blank									98.695	98.400	0.295	41.845	41.844	0.001	248.644	248.634	0.010

SOUTHWEST REGION - CORROSION-INHIBITED CHEMICAL/CONTROL SECTION

		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet A562			Cast Aluminum		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
1	6D13-34							2A	97.433	91.164	6.269	41.369	41.136	0.233	263.572	263.025	0.547
								2B	98.219	90.997	7.222	41.693	41.452	0.241	264.602	264.050	0.552
4	8D29-2							5A	97.890	94.886	3.004	41.492	41.470	0.022	256.804	256.720	0.084
								5B	98.090	94.138	3.952	41.817	41.756	0.061	264.189	264.098	0.091
Average Weight Loss - Maintenenace Trucks											**5.112**			**0.139**			**0.318**

Appendix 5

2003-04 Metal Coupon Corrosion Data

(All weight measures are in grams)

2003/2004 SALT PILOT PROJECT - CORROSION DATA																	
SOUTH CENTRAL REGION - BROWN (SALT)																	
		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet 5182			Cast Aluminum A356		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
										(grams)			(grams)			(grams)	
1	8E12-9			0	55012	62865	7853	1A	99.215	92.872	6.343	41.833	41.790	0.043	262.092	262.048	0.044
				0			0	1B	98.869	92.675	6.194	41.865	41.791	0.074	260.280	260.214	0.066
2	6E13-1			0	208800	223933	15133	2A	98.432	89.566	8.866			0.00*	261.553	261.260	0.293
				0			0	2B	98.364	86.859	11.505	41.917	41.810	0.107	260.631	260.286	0.345
Average Coupon Weight Loss - Maint. Trucks											**8.227**			**0.075**			**0.187**
3	5E20-7			0	87100	95121	8021	3A	98.381	92.940	5.441	41.807	41.702	0.105	264.623	264.386	0.237
				0			0	3B	98.562	93.232	5.330	41.838	41.731	0.107	260.902	260.661	0.241
Average Coupon Weight Loss - Sup. Truck											**5.386**			**0.106**			**0.239**
Guardrail-mounted Coupon (MP 112)									98.945	91.970	**6.975**	41.952	41.899	**0.053**	263.262	262.905	**0.357**
Control											0.000			0.000			0.000
	Ryegrass								98.615	97.303	**1.312**	41.903	41.897	**0.006**	261.209	261.163	**0.046**
Laboratory Blank								A	98.983	98.778	0.205	41.798	41.794	0.004	260.196	260.178	0.018
								B	98.722	98.453	0.269	41.896	41.891	0.005	264.499	264.485	0.014
*	panel chipped - accounts for weight discrepancy																

NORTH CENTRAL REGION - TAN (CORROSION-INHIBITED CHEMICALS)

		Hours			**Mileage**				**Cold Rolled Steel**			**Aluminum Sheet 5182**			**Cast Aluminum A356**		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
				0						(grams)			(grams)			(grams)	
1	6B13-3	3310	3528	218	83175	88159	4984	1A	99.176	96.404	2.772	41.866	41.814	0.052	265.199	265.133	0.066
				0			0	1B	98.461	95.755	2.706	41.970	41.961	0.009	259.433	259.377	0.056
2	6B13-1	3213	3417	204	84140	88788	4648	2A	98.431	95.397	3.034	41.862	41.816	0.046	266.183	266.076	0.107
				0			0	2B	98.528	95.301	3.227	41.844	41.790	0.054	263.223	263.109	0.114
3	19B8-3	2084	2423	339	34010	41848	7838	3A	98.646	94.896	3.750	41.862	41.823	0.039	263.806	263.677	0.129
				0			0	3B	98.579	95.185	3.394	41.864	41.814	0.050	262.549	262.419	0.130
5	6B13-49			0	19327	26374	7047	5A	98.664	96.050	2.614	41.751	41.715	0.036	255.758	255.673	0.085
				0			0	5B	98.751	96.175	2.576	41.841	41.811	0.030	263.568	263.510	0.058
6	6B6-10	1306	1598	292	31531	37606	6075	6A	98.649	95.556	3.093	41.901	41.788	0.113	260.960	260.794	0.166
				0			0	6B	99.006	96.375	2.631	41.918	41.828	0.090	259.129	258.922	0.207
Average Coupon Weight Loss - Maint. Trucks											**2.980**			**0.052**			**0.112**
Note: Rack #4 not used in evaluation																	
7	5B10-32			0	79042	86820	7778	7A	99.151	96.765	2.386	41.779	41.729	0.050	261.994	261.897	0.097
				0			0	7B	99.316	97.000	2.316	41.812	41.767	0.045	264.166	264.067	0.099
Average Coupon Weight Loss - Sup. Truck											**2.351**			**0.047**			**0.098**
Guardrail-mounted Coupon (MP 145)									98.966	91.728	**7.238**	41.932	41.874	**0.058**	254.477	254.031	**0.446**
Control											0.000			0.000			0.000
	Rest Area								98.946	98.474	**0.472**	41.824	41.819	**0.005**	259.795	259.784	**0.011**
											0.000			0.000			0.000
Laboratory Blank								A	98.983	98.778	0.205	41.798	41.794	0.004	260.196	260.178	0.018
								B	98.722	98.453	0.269	41.896	41.891	0.005	264.499	264.485	0.014

EASTERN REGION AREA 3 - GREEN (SALT)

		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet 5182			Cast Aluminum A356		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
										(grams)			(grams)			(grams)	
1	6G13-9	65	393	328	1773	10419	8646	1A	99.014	90.351	8.663	41.741	41.575	0.166	264.866	264.582	0.284
				0			0	1B	98.603	88.832	9.771	41.766	41.671	0.095	265.083	264.794	0.289
2	6G13-070			0	29472	36272	6800	2A	98.995	85.685	13.310	41.755	41.655	0.100	265.294	265.057	0.237
				0			0	2B	99.075	86.034	13.041	41.860	41.735	0.125	264.003	263.786	0.217
3	6G13-86			0	3872	8122	4250	3A	98.101	88.739	9.362	41.782	41.624	0.158	261.227	261.046	0.181
				0			0	3B	98.478	88.946	9.532	41.769	41.726	0.043	260.876	260.708	0.168
4	8G29-7			0	14431	17554	3123	4A	98.523	90.268	8.255	41.779	41.693	0.086	260.410	260.191	0.219
				0			0	4B	98.872	90.391	8.481	41.811	41.725	0.086	263.984	263.633	0.351
5	6G13-4	3061	3412	351	92100	102151	10051	5A	98.609	87.679	10.930			*	264.903	264.691	0.212
				0			0	5B	98.565	87.798	10.767	41.830	41.742	0.088	260.357	259.980	0.377
6	6G6-10			0	65885	68299	2414	6A	98.619	95.685	2.934	41.871	41.852	0.019	262.742	262.585	0.157
				0			0	6B	98.698	93.389	5.309	41.819	41.801	0.018	261.502	261.312	0.190
7	6G13-4	2207	2465	258	47421	52817	5396	7A	98.556	86.338	12.218	41.815	41.742	0.073	261.636	261.370	0.266
				0			0	7B	98.544	86.119	12.425	41.801	41.725	0.076	262.354	262.157	0.197
8	6G13-44			0	112835	122678	9843	8A	98.508	85.289	13.219	41.865	41.804	0.061	262.490	262.249	0.241
				0			0	8B	98.999	86.698	12.301	41.638	41.564	0.074	262.573	262.173	0.400
9	8G13-2			0	25296	30285	4989	9A	98.581	95.402	3.179	41.654	41.637	0.017	264.401	264.263	0.138
				0			0	9B	98.508	95.894	2.614	41.816	41.800	0.016	264.587	264.354	0.233
Average Coupon Weight Loss - Maint. Trucks											**9.240**			**0.077**			**0.242**
10	5G20-44			0	53756	62007	8251	10A	98.943	92.111	6.832	41.746	41.665	0.081	264.337	264.094	0.243
							0	10B	98.896	92.589	6.307	41.752	41.683	0.069	264.095	263.850	0.245
Average Coupon Weight Loss - Sup. Truck											**6.570**			**0.075**			**0.244**
Guardrail-mounted Coupon (MP 199)									98.699	90.789	**7.910**	41.884	41.838	**0.046**	254.057	253.560	**0.497**
Controls																	
	Schrag Rest Area								99.006	98.743	**0.263**	41.855	41.852	**0.003**	264.688	264.696	**-0.008**
Laboratory Blank								A	98.983	98.778	0.205	41.798	41.794	0.004	260.196	260.178	0.018
								B	98.722	98.453	0.269	41.896	41.891	0.005	264.499	264.485	0.014
*	panel chipped - accounts for weight discrepancy																

EASTERN REGION AREA 1 - WHITE (CORROSION-INHIBITED CHEMICALS)																	
		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet 5182			Cast Aluminum A356		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
										(grams)			(grams)			(grams)	
1	6G13-4	4306	4705	399	100769	109845	9076	1A	99.182	93.347	5.835	41.777	41.576	0.201	263.940	263.587	0.353
				0			0	1B	98.854	94.396	4.458	41.832	41.671	0.161	263.578	263.277	0.301
2	8G13-0	728	935	207	15002	19318	4316	2A	98.563	94.098	4.465	41.777	41.546	0.231	268.415	267.890	0.525
				0			0	2B	98.514	94.384	4.130	41.786	41.471	0.315	263.299	262.880	0.419
3	6G6-12	2858	3180	322	60997	68102	7105	3A	98.103	93.135	4.968	41.843	41.687	0.156	259.376	259.067	0.309
				0			0	3B	98.984	93.021	5.963	41.814	41.698	0.116	254.722	254.393	0.329
4	6G13-6	1869	2224	355	43358	51326	7968	4A	98.554	94.157	4.397	41.789	41.472	0.317	262.241	261.726	0.515
				0			0	4B	98.546	93.711	4.835	41.844	41.465	0.379	262.903	262.404	0.499
5	8G12-7	2253	2419	166	32999	36028	3029	5A	98.664	94.896	3.768	41.840	41.770	0.070	263.864	263.727	0.137
				0			0	5B	98.729	96.236	2.493	41.824	41.782	0.042	261.414	261.258	0.156
6	8G12-8	3687	3979	292	66233	71996	5763	6A	99.064	87.541	11.523	41.770	41.685	0.085	264.223	264.041	0.182
				0				6B	99.019	90.218	8.801	41.859	41.742	0.117	262.017	261.847	0.170
7	6G5-2	2237	2457	220	42789	46835	4046	7A	98.513	94.890	3.623	41.913	41.791	0.122	260.745	260.456	0.289
				0			0	7B	98.800	95.049	3.751	41.835	41.702	0.133	262.770	262.451	0.319
8	6G5-04	3845	4068	223	33463	36443	2980	8A	98.774	93.683	5.091	41.827	41.689	0.138	261.802	261.552	0.250
				0			0	8B	98.805	93.781	5.024	41.803	41.669	0.134	262.750	262.434	0.316
9	6G13-3	4330	4613	283	99066	102973	3907	9A	98.751	93.853	4.898	41.781	41.655	0.126	262.892	262.647	0.245
				0			0	9B	98.761	94.282	4.479	41.841	41.696	0.145	260.907	260.646	0.261
10	6G13-8	407	751	344	10496	18013	7517	10A	98.858	93.763	5.095	41.837	41.622	0.215	264.379	263.996	0.383
				0			0	10B	98.844	93.773	5.071	41.862	41.631	0.231	262.219	261.933	0.286
Average Coupon Weight Loss - Maint. Trucks											**5.133**			**0.172**			**0.312**
11	5G20-40			0	77222	83535	6313	11A	98.696	92.447	6.249	41.765	41.678	0.087	265.615	265.424	0.191
				0			0	11B	99.132	92.895	6.237	41.769	41.682	0.087	264.995	264.665	0.330
Average Coupon Weight Loss - Sup. Truck											**6.243**			**0.087**			**0.261**
Guardrail-mounted Coupon (MP Spokane City Limits)									99.170	88.588	**10.582**	41.906	41.191	**0.715**	256.305	254.653	**1.652**
Controls																	
	County Line Rest Area								99.211	98.921	**0.290**	41.964	41.955	**0.009**	262.938	262.922	**0.016**
Laboratory Blank								A	98.983	98.778	0.205	41.798	41.794	0.004	260.196	260.178	0.018
								B	98.722	98.453	0.269	41.896	41.891	0.005	264.499	264.485	0.014

SOUTHWEST REGION - BLACK (SALT)																	
		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet 5182			Cast Aluminum A356		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
									(grams)			(grams)			(grams)		
1	8D29-4			0			0	1A	98.682	94.480	4.202	41.905	41.829	0.076	260.264	260.152	0.112
				0			0	1B	98.703	94.211	4.492	41.801	41.752	0.049	263.824	263.698	0.126
2	6D6-95			0			0	2A	98.661	93.351	5.310	41.826	41.793	0.033	260.982	260.919	0.063
				0			0	2B	98.835	94.221	4.614	41.766	41.736	0.030	262.766	262.716	0.050
Average Coupon Weight Loss - Maint. Trucks											**4.655**			**0.047**			**0.088**
SOUTHWEST REGION - BLACK (CORROSION-INHIBITED CHEMICALS)																	
		Hours			Mileage				Cold Rolled Steel			Aluminum Sheet 5182			Cast Aluminum A356		
Rack	Equip #	start	end	diff	start	end	diff	Panel	start wt	end wt	change	start wt	end wt	change	start wt	end wt	change
									(grams)			(grams)			(grams)		
3	6D13-34			0			0	3A	98.884	91.325	7.559	41.717	41.609	0.108	262.721	262.557	0.164
				0			0	3B	98.812	90.373	8.439	41.709	41.577	0.132	266.719	266.515	0.204
4	8D29-2			0			0	4A	98.492	93.088	5.404	41.748	41.700	0.048	262.806	262.714	0.092
				0			0	4B	98.676	93.830	4.846	41.783	41.750	0.033	260.027	259.909	0.118
Average Coupon Weight Loss - Maint. Trucks											**6.562**			**0.080**			**0.144**
Guardrail-mounted Coupon									99.309	91.891	**7.418**	41.938	41.930	**0.008**	259.759	259.702	**0.057**
Controls																	
	Remote								98.288	98.075	**0.213**	41.907	41.900	**0.007**	260.224	260.204	**0.020**
Laboratory Blank								A	98.983	98.778	0.205	41.798	41.794	0.004	260.196	260.178	0.018
								B	98.722	98.453	0.269	41.896	41.891	0.005	264.499	264.485	0.014

Appendix 6 2002-04 Environmental Sampling Data

SC REGION SALT SECTION

Sample ID #	Matrix	Pre-winter 2002 Total Chloride (mg/kg)	Post-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Cyanide (mg/l)	Post-winter 2004 Total Chloride (mg/kg)	Post-winter 2004 Total Cyanide (mg/l)
1-1-1	Solid	18.1	21.2	70.70	ND	30.00	ND
1-2-1	Solid	56.8	16.3	58.50	ND	55.00	ND
1-3-1	Solid	4.16	10.6	18.00	ND	28.00	ND
Avg.				**49.07**		**37.67**	
1-1-2	Solid	18.8	68.1	25.90	ND	30.00	ND
1-2-2	Solid	2.59	8.71	24.30	ND	35.00	ND
1-3-2	Solid	65	8.97	21.80	ND	15.00	ND
Avg.				**24.00**		**26.67**	
1-1-3	Solid	13.5	18.3	7.10	0.3	10.00	ND
1-2-3	Solid	3.41	15.4	156.00	ND	10.00	ND
Avg.				**81.55**		**10.00**	
1-C-RA	Solid	1.11	1.9	ND	ND	10.00	ND
1-4-1	Solid	8.47	*	*	*	*	*
1-4-2	Solid	ND	*	*	*	*	*
1-RA-DW	Liquid	4.52	5.45	5.13	ND	6.00	ND

EASTERN REGION SALT SECTION

Sample ID #	Matrix	Pre-winter 2002 Total Chloride (mg/kg)	Post-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Cyanide (mg/l)	Post-winter 2004 Total Chloride (mg/kg)	Post-winter 2004 Total Cyanide (mg/l)
3-1-1	Solid	7.75	ND	2.14	ND	15.00	ND
3-2-1	Solid	2.78	ND	7.02	ND	18.00	ND
3-3-1	Solid	2.14	3.07	3.12	ND	15.00	ND
3-4-1	Solid	5.77	8.98	5.43	ND	10.00	ND
Avg.				**4.43**		**14.50**	
3-1-2	Solid	41.1	29.2	994.00	ND	15.00	ND
3-2-2	Solid	7.75	7.21	62.70	ND	55.00	ND
3-3-2	Solid	7.74	13.8	0.00	ND	15.00	ND
3-4-2	Solid	51.4	2.5	15.10	ND	0.00	ND
Avg.				**267.95**		**21.25**	
3-4-3	Solid	177	190	**97.20**	ND	**10.00**	ND
3-C-RA	Solid	1.03	207	3.56	ND	15.00	ND
3-4-W	Liquid	228	165		ND	110.00	ND
3-RA-DW	Liquid	127	144	113.00	ND	147.00	ND

SW REGION SALT SECTION

Sample ID #	Matrix	Pre-winter 2002 Total Chloride (mg/kg)	Post-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Cyanide (mg/l)	Post-winter 2004 Total Chloride (mg/kg)
1-1	Solid	10.6	ND	6.2		9.1
1-2	Solid	643	5.06	112		44.9
1-3	Solid	203	14.3	9.9		111
1-4	Liquid	23.7	2.78	18.8		3.92
2-1	Solid	13.4	1.86	20.2		6.6
2-2	Solid	173	12	87		20.1
2-4	Liquid	11.4	2.75	8.55		5.4

NC REGION CORROSION INHIBITED CHEMICAL SECTION

Sample ID #	Matrix	Pre-winter 2002 Total Chloride (mg/kg)	Post-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Cyanide (mg/l)	Post-winter 2004 Total Chloride (mg/kg)	Post-winter 2004 Total Cyanide (mg/l)
2-1-1	Solid	4.59	21.4	29.80	ND	18.00	ND
2-2-1	Solid	2.27	15.1	8.72	ND	18.00	ND
2-4-1	Solid	212	77.4	198.00	ND	40.00	ND
Avg.				**78.84**		**25.33**	
2-1-2	Solid	13.9	35.3	208.00	ND	10.00	ND
2-2-2	Solid	42.9	128	153.00	ND	12.00	ND
2-4-2	Solid	38.9	42.2	12.90	ND	0.00	ND
Avg.				**124.63**		**7.33**	
2-1-3	Solid	138	7.64	931.00	ND	30.00	ND
2-2-3	Solid	2.76	200	298.00	ND	12.00	ND
Avg.				**614.50**		**21.00**	
2-C-RA	Solid	2.13	ND	ND	ND	10.00	ND
2-3-1	Solid	227	*	*	*	*	*
2-3-2	Solid	96.8	*	*	*	*	*
2-3-3	Solid	330	*	*	*	*	*
2-RA-DW	Liquid	9.07	9.17	8.29	ND	9.50	ND
2-1-W	Liquid	21.5	28.5	28.10	ND	45.00	ND
2-2-W	Liquid	3.99	6.38	6.24	ND	10.00	ND
2-4-W	Liquid	2.78	1.94	3.23	ND	4.50	ND
Avg.				**12.52**		**19.83**	
2-3-W	Liquid	3.59	*	*	*	*	*

EASTERN REGION CORROSION INHIBITED CHEMICAL SECTION

Sample ID #	Matrix	Pre-winter 2002 Total Chloride (mg/kg)	Post-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Chloride (mg/kg)	Pre-winter 2003 Total Cyanide (mg/l)	Post-winter 2004 Total Chloride (mg/kg)	Post-winter 2004 Total Cyanide (mg/l)
4-1-1	Solid	ND	ND	8.64	ND	0.00	ND
4-2-1	Solid	253	ND	78.70	ND	15.00	ND
4-3-1	Solid	ND	ND	10.40	ND	12.00	ND
4-4-1	Solid	1210	645	6.36	ND	10.00	ND
Avg.				**26.03**		**9.25**	
4-1-2	Solid	6.01	ND	17.50	ND	0.00	ND
4-2-2	Solid	4.47	3.39	6.34	ND	0.00	ND
4-3-2	Solid	ND	ND	40.60	ND	0.00	ND
4-4-2	Solid	2.1	8.06	0.00	ND	10.00	ND
Avg.				**16.11**		**2.50**	
4-1-3	Solid	107	100	717.00	ND	92.00	ND
4-2-3	Solid	8.55	13.8	12.80	ND	22.00	ND
Avg.				**364.90**		**57.00**	
4-C-RA	Solid	ND	1.74	ND	ND	ND	ND
4-2-W	Liquid	30.8	43.2	36.00	ND	86.00	ND
4-RA-DW	Liquid	0.989	2.38	8.70	ND	4.00	ND